

Revised First Edition

Machinery's Handbook Pocket Companion

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A REFERENCE BOOK
FOR THE MECHANICAL ENGINEER, DESIGNER,
MANUFACTURING ENGINEER, DRAFTSMAN,
TOOLMAKER, AND MACHINIST

Machinery's Handbook Pocket Companion

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Machinery's Handbook Pocket Companion

Revised First Edition

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Foreword

This volume has been prepared for the many users of *Machinery's Handbook* who indicated the need for a smaller, more convenient reference that provides immediate application of fundamental and reliable data used by practitioners and students of the machine trades.

Machinery's Handbook Pocket Companion is a tool designed to provide years of bench-side use. With its visual presentation and detailed information, it can be used daily and quickly to save time and labor. Parts of the presented material have been carefully selected from current and former editions of *Machinery's Handbook*. Some of the subject matter has been reorganized, distilled, or simplified to increase the usefulness of this book without adding to its bulk.

To obtain the full value of this small handbook, the user must have sufficient knowledge about the subject to apply the tables, formulas, and other data, whenever they can be used with efficiency. *Machinery's Handbook Pocket Companion* makes little attempt to explain the various subjects in any detail. The publisher assumes that users of this handbook are acquainted with information and procedures necessary for the safe operation and manipulation of machines and tools. Readers who require in-depth information, background on manufacturing operations and theory should refer to *Machinery's Handbook*.

Various people have leant their support and expertise to this work. Acknowledgments and thanks are due to Ken Evans of Layton, Utah, and editors emeritus of *Machinery's Handbook*, Henry Ryffel and Robert Green, for manuscript review and many helpful suggestions. The generous efforts of Alex Luchars and John Carleo of Industrial Press are greatly appreciated.

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Special acknowledgments are due to Carr-Lane Manufacturing Company, The Norton Company, and Sandvik Coromant Company for permission to use their material and for the business courtesies they extended to the editors.

Finally, thanks to all the individuals, associations, societies, educational institutions, firms and their employees for providing invaluable technical information and illustration material for this book.

Anyone with suggestions for improving this book is requested to communicate in writing with Industrial Press. Alternatively, the editors can be contacted through e-mail at info@industrialpress.com, or through its web site: www.industrialpress.com.

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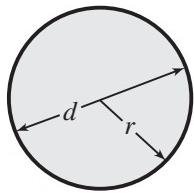
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MATHEMATICAL FORMULAS AND TABLES

Areas and Dimensions of Plane Figures

Circle:



$$\text{Area} = A = \pi r^2 = 3.1416 r^2 = 0.7854 d^2$$

$$\text{Circumference} = C = 2\pi r = 6.2832 r = 3.1416 d$$

$$r = C \div 6.2832 = \sqrt{A \div 3.1416} = 0.564 \sqrt{A}$$

$$d = C \div 3.1416 = \sqrt{A \div 0.7854} = 1.128 \sqrt{A}$$

$$\text{Length of arc for center angle of } 1^\circ = 0.008727 d$$

$$\text{Length of arc for center angle of } n^\circ = 0.008727 n d$$

Example: Find the area A and circumference C of a circle with a diameter of $2\frac{3}{4}$ inches.

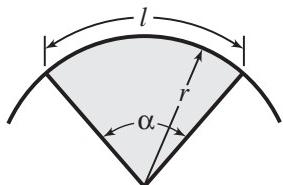
$$A = 0.7854 d^2 = 0.7854 \times 2.75^2 = 0.7854 \times 2.75 \times 2.75 = 5.9396 \text{ square inches}$$

$$C = 3.1416 d = 3.1416 \times 2.75 = 8.6394 \text{ inches}$$

Example: The area of a circle is 16.8 square inches. Find its diameter.

$$d = 1.128 \sqrt{A} = 1.128 \sqrt{16.8} = 1.128 \times 4.099 = 4.624 \text{ inches}$$

Circular Sector:



$$\text{Length of arc} = l = \frac{r \times \alpha \times 3.1416}{180} = 0.01745 r \alpha = \frac{2A}{r}$$

$$\text{Area} = A = \frac{1}{2} r l = 0.008727 \alpha r^2$$

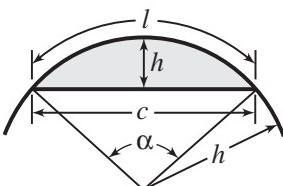
$$\text{Angle, in degrees} = \alpha = \frac{57.296 l}{r} \quad r = \frac{2A}{l} = \frac{57.296 l}{\alpha}$$

Example: The radius of a circle is 35 millimeters, and angle α of a sector of the circle is 60 degrees. Find the area of the sector and the length of arc l .

$$A = 0.008727 \alpha r^2 = 0.008727 \times 60 \times 35^2 = 641.41 \text{ mm}^2 = 6.41 \text{ cm}^2$$

$$l = 0.01745 r \alpha = 0.01745 \times 35 \times 60 = 36.645 \text{ millimeters}$$

Circular Segment:



$$A = \text{area} \quad l = \text{length of arc} \quad \alpha = \text{angle, in degrees}$$

$$c = 2\sqrt{h(2r-h)} \quad A = \frac{1}{2}[rl - c(r-h)]$$

$$r = \frac{c^2 + 4h^2}{8h} \quad l = 0.01745 r \alpha$$

$$h = r - \frac{1}{2}\sqrt{4r^2 - c^2} = r[1 - \cos(\alpha/2)] \quad \alpha = \frac{57.296 l}{r}$$

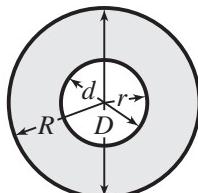
Example: The radius r is 60 inches and the height h is 8 inches. Find the length of the chord c .

$$c = 2\sqrt{h(2r-h)} = 2\sqrt{8 \times (2 \times 60 - 8)} = 2\sqrt{896} = 2 \times 29.93 = 59.86 \text{ inches}$$

Example: If $c = 16$, and $h = 6$ inches, what is the radius of the circle of which the segment is a part?

$$r = \frac{c^2 + 4h^2}{8h} = \frac{16^2 + 4 \times 6^2}{8 \times 6} = \frac{256 + 144}{48} = \frac{400}{48} = 8\frac{1}{3} \text{ inches}$$

Circular Ring:



$$\begin{aligned} \text{Area} = A &= \pi(R^2 - r^2) = 3.1416(R^2 - r^2) \\ &= 3.1416(R+r)(R-r) \\ &= 0.7854(D^2 - d^2) = 0.7854(D+d)(D-d) \end{aligned}$$

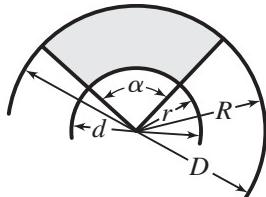
Circular Ring (Continued)

Example: Let the outside diameter $D = 12$ centimeters and the inside diameter $d = 8$ centimeters. Find the area of the ring.

$$\begin{aligned} A &= 0.7854(D^2 - d^2) = 0.7854(12^2 - 8^2) = 0.7854(144 - 64) = 0.7854 \times 80 \\ &= 62.83 \text{ square centimeters} \end{aligned}$$

By the alternative formula:

$$\begin{aligned} A &= 0.7854(D + d)(D - d) = 0.7854(12 + 8)(12 - 8) = 0.7854 \times 20 \times 4 \\ &= 62.83 \text{ square centimeters} \end{aligned}$$

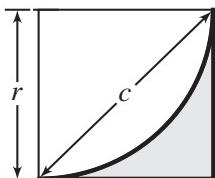
Circular Ring Sector:

A = area α = angle, in degrees

$$\begin{aligned} A &= \frac{\alpha\pi}{360}(R^2 - r^2) = 0.00873\alpha(R^2 - r^2) \\ &= \frac{\alpha\pi}{4 \times 360}(D^2 - d^2) = 0.00218\alpha(D^2 - d^2) \end{aligned}$$

Example: Find the area, if the outside radius $R = 5$ inches, the inside radius $r = 2$ inches, and $\alpha = 72$ degrees.

$$\begin{aligned} A &= 0.00873\alpha(R^2 - r^2) = 0.00873 \times 72(5^2 - 2^2) \\ &= 0.6286(25 - 4) = 0.6286 \times 21 = 13.2 \text{ square inches} \end{aligned}$$

Spandrel or Fillet:

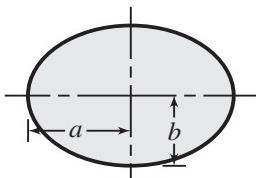
$$\text{Area} = A = r^2 - \frac{\pi r^2}{4} = 0.215r^2 = 0.1075c^2$$

Example: Find the area of a spandrel, the radius of which is 0.7 inch.

$$A = 0.215r^2 = 0.215 \times 0.7^2 = 0.105 \text{ square inch}$$

Example: If chord c were given as 2.2 inches, what would be the area?

$$A = 0.1075c^2 = 0.1075 \times 2.2^2 = 0.520 \text{ square inch}$$

Ellipse:

$$\text{Area} = A = \pi ab = 3.1416ab$$

An approximate formula for the perimeter is

$$\text{Perimeter} = P = 3.1416\sqrt{2(a^2 + b^2)}$$

$$\text{A closer approximation is } P = 3.1416\sqrt{2(a^2 + b^2) - \frac{(a-b)^2}{2.2}}$$

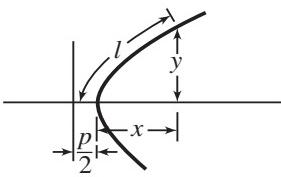
Example: The larger or major axis is 200 millimeters. The smaller or minor axis is 150 millimeters. Find the area and the approximate circumference. Here, then, $a = 100$, and $b = 75$.

$$A = 3.1416ab = 3.1416 \times 100 \times 75 = 23,562 \text{ square millimeters} = 235.62 \text{ square centimeters}$$

$$P = 3.1416\sqrt{2(a^2 + b^2)} = 3.1416\sqrt{2(100^2 + 75^2)} = 3.1416\sqrt{2 \times 15,625}$$

$$= 3.1416\sqrt{31,250} = 3.1416 \times 176.78 = 555.37 \text{ millimeters} = (55.537 \text{ centimeters})$$

Parabola:



$$l = \text{length of arc} = \frac{p}{2} \left[\sqrt{\frac{2x}{p}} \left(1 + \frac{2x}{p} \right) + \ln \left(\sqrt{\frac{2x}{p}} + \sqrt{1 + \frac{2x}{p}} \right) \right]$$

When x is small in proportion to y , the following is a close approximation:

$$l = y \left[1 + \frac{2}{3} \left(\frac{x}{y} \right)^2 - \frac{2}{5} \left(\frac{x}{y} \right)^4 \right] \text{ or } l = \sqrt{y^2 + \frac{4}{3}x^2}$$

Example: If $x = 2$ and $y = 24$ feet, what is the approximate length l of the parabolic curve?

$$\begin{aligned} l &= y \left[1 + \frac{2}{3} \left(\frac{x}{y} \right)^2 - \frac{2}{5} \left(\frac{x}{y} \right)^4 \right] = 24 \left[1 + \frac{2}{3} \left(\frac{2}{24} \right)^2 - \frac{2}{5} \left(\frac{2}{24} \right)^4 \right] \\ &= 24 \left[1 + \frac{2}{3} \times \frac{1}{144} - \frac{2}{5} \times \frac{1}{20,736} \right] = 24 \times 1.0046 = 24.11 \text{ feet} \end{aligned}$$

Formulas and Table for Regular Polygons.—The following formulas and table can be used to calculate the area, length of side, and radii of the inscribed and circumscribed circles of regular polygons (equal sided).

$$A = NS^2 \cot \alpha \div 4 = NR^2 \sin \alpha \cos \alpha = Nr^2 \tan \alpha$$

$$r = R \cos \alpha = (S \cot \alpha) \div 2 = \sqrt{(A \times \cot \alpha) \div N}$$

$$R = S \div (2 \sin \alpha) = r \div \cos \alpha = \sqrt{A \div (N \sin \alpha \cos \alpha)}$$

$$S = 2R \sin \alpha = 2r \tan \alpha = 2\sqrt{(A \times \tan \alpha) \div N}$$

where N = number of sides

S = length of side

R = radius of circumscribed circle

r = radius of inscribed circle

A = area of polygon

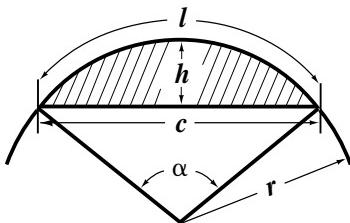
$\alpha = 180^\circ \div N$ = one-half center angle of one side

Area, Length of Side, and Inscribed and Circumscribed Radii of Regular Polygons

| No. of Sides | $\frac{A}{S^2}$ | $\frac{A}{R^2}$ | $\frac{A}{r^2}$ | $\frac{R}{S}$ | $\frac{R}{r}$ | $\frac{S}{R}$ | $\frac{S}{r}$ | $\frac{r}{R}$ | $\frac{r}{S}$ |
|--------------------|-----------------|-----------------|-----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 3 | 0.4330 | 1.2990 | 5.1962 | 0.5774 | 2.0000 | 1.7321 | 3.4641 | 0.5000 | 0.2887 |
| 4 | 1.0000 | 2.0000 | 4.0000 | 0.7071 | 1.4142 | 1.4142 | 2.0000 | 0.7071 | 0.5000 |
| 5 | 1.7205 | 2.3776 | 3.6327 | 0.8507 | 1.2361 | 1.1756 | 1.4531 | 0.8090 | 0.6882 |
| 6 | 2.5981 | 2.5981 | 3.4641 | 1.0000 | 1.1547 | 1.0000 | 1.1547 | 0.8660 | 0.8660 |
| 7 | 3.6339 | 2.7364 | 3.3710 | 1.1524 | 1.1099 | 0.8678 | 0.9631 | 0.9010 | 1.0383 |
| 8 | 4.8284 | 2.8284 | 3.3137 | 1.3066 | 1.0824 | 0.7654 | 0.8284 | 0.9239 | 1.2071 |
| 9 | 6.1818 | 2.8925 | 3.2757 | 1.4619 | 1.0642 | 0.6840 | 0.7279 | 0.9397 | 1.3737 |
| 10 | 7.6942 | 2.9389 | 3.2492 | 1.6180 | 1.0515 | 0.6180 | 0.6498 | 0.9511 | 1.5388 |
| 12 | 11.196 | 3.0000 | 3.2154 | 1.9319 | 1.0353 | 0.5176 | 0.5359 | 0.9659 | 1.8660 |
| 16 | 20.109 | 3.0615 | 3.1826 | 2.5629 | 1.0196 | 0.3902 | 0.3978 | 0.9808 | 2.5137 |
| 20 | 31.569 | 3.0902 | 3.1677 | 3.1962 | 1.0125 | 0.3129 | 0.3168 | 0.9877 | 3.1569 |
| 24 | 45.575 | 3.1058 | 3.1597 | 3.8306 | 1.0086 | 0.2611 | 0.2633 | 0.9914 | 3.7979 |
| 32 | 81.225 | 3.1214 | 3.1517 | 5.1011 | 1.0048 | 0.1960 | 0.1970 | 0.9952 | 5.0766 |
| 48 | 183.08 | 3.1326 | 3.1461 | 7.6449 | 1.0021 | 0.1308 | 0.1311 | 0.9979 | 7.6285 |
| 64 | 325.69 | 3.1365 | 3.1441 | 10.190 | 1.0012 | 0.0981 | 0.0983 | 0.9988 | 10.178 |

SEGMENTS OF CIRCLES

Segments of Circles for Radius = 1 (English or metric units)



Formulas for segments of circles are given on page 1. When the central angle α and radius r are known, the tables on these pages can be used to find the length of arc l , height of segment h , chord length c , and segment area A . When angle α and radius r are not known, but segment height h and chord length c are known or can be measured, the ratio h/c can be used to enter the table and find α , l , and A by linear interpolation. Radius r is found by the formula on page 1. The value of l is then multiplied by the radius r and the area A by r^2 , the square of the radius.

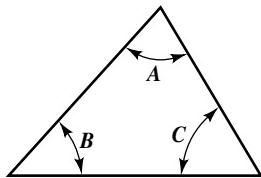
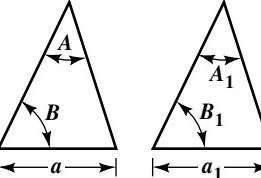
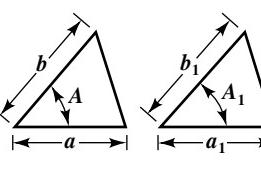
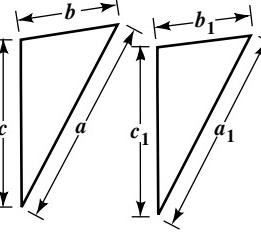
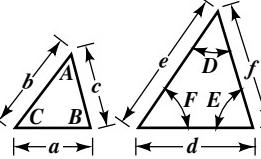
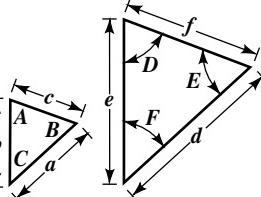
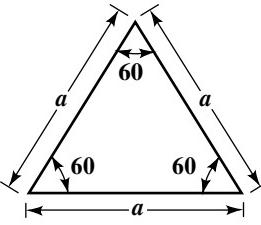
Angle α can be found thus with an accuracy of about 0.001 degree; arc length l with an error of about 0.02 per cent; and area A with an error ranging from about 0.02 per cent for the highest entry value of h/c to about 1 per cent for values of h/c of about 0.050. For lower values of h/c , and where greater accuracy is required, area A should be found by the formula on page 1.

| θ , Deg. | l | h | c | Area A | h/c | θ , Deg. | l | h | c | Area A | h/c |
|--------------------|---------|---------|---------|----------|---------|--------------------|---------|---------|---------|----------|---------|
| 1 | 0.01745 | 0.00004 | 0.01745 | 0.0000 | 0.00218 | 41 | 0.71558 | 0.06333 | 0.70041 | 0.0298 | 0.09041 |
| 2 | 0.03491 | 0.00015 | 0.03490 | 0.0000 | 0.00436 | 42 | 0.73304 | 0.06642 | 0.71674 | 0.0320 | 0.09267 |
| 3 | 0.05236 | 0.00034 | 0.05235 | 0.0000 | 0.00655 | 43 | 0.75049 | 0.06958 | 0.73300 | 0.0342 | 0.09493 |
| 4 | 0.06981 | 0.00061 | 0.06980 | 0.0000 | 0.00873 | 44 | 0.76794 | 0.07282 | 0.74921 | 0.0366 | 0.09719 |
| 5 | 0.08727 | 0.00095 | 0.08724 | 0.0001 | 0.01091 | 45 | 0.78540 | 0.07612 | 0.76537 | 0.0391 | 0.09946 |
| 6 | 0.10472 | 0.00137 | 0.10467 | 0.0001 | 0.01309 | 46 | 0.80285 | 0.07950 | 0.78146 | 0.0418 | 0.10173 |
| 7 | 0.12217 | 0.00187 | 0.12210 | 0.0002 | 0.01528 | 47 | 0.82030 | 0.08294 | 0.79750 | 0.0445 | 0.10400 |
| 8 | 0.13963 | 0.00244 | 0.13951 | 0.0002 | 0.01746 | 48 | 0.83776 | 0.08645 | 0.81347 | 0.0473 | 0.10628 |
| 9 | 0.15708 | 0.00308 | 0.15692 | 0.0003 | 0.01965 | 49 | 0.85521 | 0.09004 | 0.82939 | 0.0503 | 0.10856 |
| 10 | 0.17453 | 0.00381 | 0.17431 | 0.0004 | 0.02183 | 50 | 0.87266 | 0.09369 | 0.84524 | 0.0533 | 0.11085 |
| 11 | 0.19199 | 0.00460 | 0.19169 | 0.0006 | 0.02402 | 51 | 0.89012 | 0.09741 | 0.86102 | 0.0565 | 0.11314 |
| 12 | 0.20944 | 0.00548 | 0.20906 | 0.0008 | 0.02620 | 52 | 0.90757 | 0.10121 | 0.87674 | 0.0598 | 0.11543 |
| 13 | 0.22689 | 0.00643 | 0.22641 | 0.0010 | 0.02839 | 53 | 0.92502 | 0.10507 | 0.89240 | 0.0632 | 0.11773 |
| 14 | 0.24435 | 0.00745 | 0.24374 | 0.0012 | 0.03058 | 54 | 0.94248 | 0.10899 | 0.90798 | 0.0667 | 0.12004 |
| 15 | 0.26180 | 0.00856 | 0.26105 | 0.0015 | 0.03277 | 55 | 0.95993 | 0.11299 | 0.92350 | 0.0704 | 0.12235 |
| 16 | 0.27925 | 0.00973 | 0.27835 | 0.0018 | 0.03496 | 56 | 0.97738 | 0.11705 | 0.93894 | 0.0742 | 0.12466 |
| 17 | 0.29671 | 0.01098 | 0.29562 | 0.0022 | 0.03716 | 57 | 0.99484 | 0.12118 | 0.95432 | 0.0781 | 0.12698 |
| 18 | 0.31416 | 0.01231 | 0.31287 | 0.0026 | 0.03935 | 58 | 1.01229 | 0.12538 | 0.96962 | 0.0821 | 0.12931 |
| 19 | 0.33161 | 0.01371 | 0.33010 | 0.0030 | 0.04155 | 59 | 1.02974 | 0.12964 | 0.98485 | 0.0863 | 0.13164 |
| 20 | 0.34907 | 0.01519 | 0.34730 | 0.0035 | 0.04374 | 60 | 1.04720 | 0.13397 | 1.00000 | 0.0906 | 0.13397 |
| 21 | 0.36652 | 0.01675 | 0.36447 | 0.0041 | 0.04594 | 61 | 1.06465 | 0.13837 | 1.01508 | 0.0950 | 0.13632 |
| 22 | 0.38397 | 0.01837 | 0.38162 | 0.0047 | 0.04814 | 62 | 1.08210 | 0.14283 | 1.03008 | 0.0996 | 0.13866 |
| 23 | 0.40143 | 0.02008 | 0.39874 | 0.0053 | 0.05035 | 63 | 1.09956 | 0.14736 | 1.04500 | 0.1043 | 0.14101 |
| 24 | 0.41888 | 0.02185 | 0.41582 | 0.0061 | 0.05255 | 64 | 1.11701 | 0.15195 | 1.05984 | 0.1091 | 0.14337 |
| 25 | 0.43633 | 0.02370 | 0.43288 | 0.0069 | 0.05476 | 65 | 1.13446 | 0.15661 | 1.07460 | 0.1141 | 0.14574 |
| 26 | 0.45379 | 0.02563 | 0.44990 | 0.0077 | 0.05697 | 66 | 1.15192 | 0.16133 | 1.08928 | 0.1192 | 0.14811 |
| 27 | 0.47124 | 0.02763 | 0.46689 | 0.0086 | 0.05918 | 67 | 1.16937 | 0.16611 | 1.10387 | 0.1244 | 0.15048 |
| 28 | 0.48869 | 0.02970 | 0.48384 | 0.0096 | 0.06139 | 68 | 1.18682 | 0.17096 | 1.11839 | 0.1298 | 0.15287 |
| 29 | 0.50615 | 0.03185 | 0.50076 | 0.0107 | 0.06361 | 69 | 1.20428 | 0.17587 | 1.13281 | 0.1353 | 0.15525 |
| 30 | 0.52360 | 0.03407 | 0.51764 | 0.0118 | 0.06583 | 70 | 1.22173 | 0.18085 | 1.14715 | 0.1410 | 0.15765 |
| 31 | 0.54105 | 0.03637 | 0.53448 | 0.0130 | 0.06805 | 71 | 1.23918 | 0.18588 | 1.16141 | 0.1468 | 0.16005 |
| 32 | 0.55851 | 0.03874 | 0.55127 | 0.0143 | 0.07027 | 72 | 1.25664 | 0.19098 | 1.17557 | 0.1528 | 0.16246 |
| 33 | 0.57596 | 0.04118 | 0.56803 | 0.0157 | 0.07250 | 73 | 1.27409 | 0.19614 | 1.18965 | 0.1589 | 0.16488 |
| 34 | 0.59341 | 0.04370 | 0.58474 | 0.0171 | 0.07473 | 74 | 1.29154 | 0.20136 | 1.20363 | 0.1651 | 0.16730 |
| 35 | 0.61087 | 0.04628 | 0.60141 | 0.0186 | 0.07696 | 75 | 1.30900 | 0.20665 | 1.21752 | 0.1715 | 0.16973 |
| 36 | 0.62832 | 0.04894 | 0.61803 | 0.0203 | 0.07919 | 76 | 1.32645 | 0.21199 | 1.23132 | 0.1781 | 0.17216 |
| 37 | 0.64577 | 0.05168 | 0.63461 | 0.0220 | 0.08143 | 77 | 1.34390 | 0.21739 | 1.24503 | 0.1848 | 0.17461 |
| 38 | 0.66323 | 0.05448 | 0.65114 | 0.0238 | 0.08367 | 78 | 1.36136 | 0.22285 | 1.25864 | 0.1916 | 0.17706 |
| 39 | 0.68068 | 0.05736 | 0.66761 | 0.0257 | 0.08592 | 79 | 1.37881 | 0.22838 | 1.27216 | 0.1986 | 0.17952 |
| 40 | 0.69813 | 0.06031 | 0.68404 | 0.0277 | 0.08816 | 80 | 1.39626 | 0.23396 | 1.28558 | 0.2057 | 0.18199 |

(Continued) Segments of Circles for Radius = 1 (English or metric units)

| θ , Deg. | l | h | c | $Area\ A$ | h/c | θ , Deg. | l | h | c | $Area\ A$ | h/c |
|--------------------|---------|---------|---------|-----------|---------|--------------------|---------|---------|---------|-----------|---------|
| 81 | 1.41372 | 0.23959 | 1.29890 | 0.2130 | 0.18446 | 131 | 2.28638 | 0.58531 | 1.81992 | 0.7658 | 0.32161 |
| 82 | 1.43117 | 0.24529 | 1.31212 | 0.2205 | 0.18694 | 132 | 2.30383 | 0.59326 | 1.82709 | 0.7803 | 0.32470 |
| 83 | 1.44862 | 0.25104 | 1.32524 | 0.2280 | 0.18943 | 133 | 2.32129 | 0.60125 | 1.83412 | 0.7950 | 0.32781 |
| 84 | 1.46608 | 0.25686 | 1.33826 | 0.2358 | 0.19193 | 134 | 2.33874 | 0.60927 | 1.84101 | 0.8097 | 0.33094 |
| 85 | 1.48353 | 0.26272 | 1.35118 | 0.2437 | 0.19444 | 135 | 2.35619 | 0.61732 | 1.84776 | 0.8245 | 0.33409 |
| 86 | 1.50098 | 0.26865 | 1.36400 | 0.2517 | 0.19696 | 136 | 2.37365 | 0.62539 | 1.85437 | 0.8395 | 0.33725 |
| 87 | 1.51844 | 0.27463 | 1.37671 | 0.2599 | 0.19948 | 137 | 2.39110 | 0.63350 | 1.86084 | 0.8546 | 0.34044 |
| 88 | 1.53589 | 0.28066 | 1.38932 | 0.2682 | 0.20201 | 138 | 2.40855 | 0.64163 | 1.86716 | 0.8697 | 0.34364 |
| 89 | 1.55334 | 0.28675 | 1.40182 | 0.2767 | 0.20456 | 139 | 2.42601 | 0.64979 | 1.87334 | 0.8850 | 0.34686 |
| 90 | 1.57080 | 0.29289 | 1.41421 | 0.2854 | 0.20711 | 140 | 2.44346 | 0.65798 | 1.87939 | 0.9003 | 0.35010 |
| 91 | 1.58825 | 0.29909 | 1.42650 | 0.2942 | 0.20967 | 141 | 2.46091 | 0.66619 | 1.88528 | 0.9158 | 0.35337 |
| 92 | 1.60570 | 0.30534 | 1.43868 | 0.3032 | 0.21224 | 142 | 2.47837 | 0.67443 | 1.89104 | 0.9314 | 0.35665 |
| 93 | 1.62316 | 0.31165 | 1.45075 | 0.3123 | 0.21482 | 143 | 2.49582 | 0.68270 | 1.89665 | 0.9470 | 0.35995 |
| 94 | 1.64061 | 0.31800 | 1.46271 | 0.3215 | 0.21741 | 144 | 2.51327 | 0.69098 | 1.90211 | 0.9627 | 0.36327 |
| 95 | 1.65806 | 0.32441 | 1.47455 | 0.3309 | 0.22001 | 145 | 2.53073 | 0.69929 | 1.90743 | 0.9786 | 0.36662 |
| 96 | 1.67552 | 0.33087 | 1.48629 | 0.3405 | 0.22261 | 146 | 2.54818 | 0.70763 | 1.91261 | 0.9945 | 0.36998 |
| 97 | 1.69297 | 0.33738 | 1.49791 | 0.3502 | 0.22523 | 147 | 2.56563 | 0.71598 | 1.91764 | 1.0105 | 0.37337 |
| 98 | 1.71042 | 0.34394 | 1.50942 | 0.3601 | 0.22786 | 148 | 2.58309 | 0.72436 | 1.92252 | 1.0266 | 0.37678 |
| 99 | 1.72788 | 0.35055 | 1.52081 | 0.3701 | 0.23050 | 149 | 2.60054 | 0.73276 | 1.92726 | 1.0428 | 0.38021 |
| 100 | 1.74533 | 0.35721 | 1.53209 | 0.3803 | 0.23315 | 150 | 2.61799 | 0.74118 | 1.93185 | 1.0590 | 0.38366 |
| 101 | 1.76278 | 0.36392 | 1.54325 | 0.3906 | 0.23582 | 151 | 2.63545 | 0.74962 | 1.93630 | 1.0753 | 0.38714 |
| 102 | 1.78024 | 0.37068 | 1.55429 | 0.4010 | 0.23849 | 152 | 2.65290 | 0.75808 | 1.94059 | 1.0917 | 0.39064 |
| 103 | 1.79769 | 0.37749 | 1.56522 | 0.4117 | 0.24117 | 153 | 2.67035 | 0.76655 | 1.94474 | 1.1082 | 0.39417 |
| 104 | 1.81514 | 0.38434 | 1.57602 | 0.4224 | 0.24387 | 154 | 2.68781 | 0.77505 | 1.94874 | 1.1247 | 0.39772 |
| 105 | 1.83260 | 0.39124 | 1.58671 | 0.4333 | 0.24657 | 155 | 2.70526 | 0.78356 | 1.95259 | 1.1413 | 0.40129 |
| 106 | 1.85005 | 0.39818 | 1.59727 | 0.4444 | 0.24929 | 156 | 2.72271 | 0.79209 | 1.95630 | 1.1580 | 0.40489 |
| 107 | 1.86750 | 0.40518 | 1.60771 | 0.4556 | 0.25202 | 157 | 2.74017 | 0.80063 | 1.95985 | 1.1747 | 0.40852 |
| 108 | 1.88496 | 0.41221 | 1.61803 | 0.4669 | 0.25476 | 158 | 2.75762 | 0.80919 | 1.96325 | 1.1915 | 0.41217 |
| 109 | 1.90241 | 0.41930 | 1.62823 | 0.4784 | 0.25752 | 159 | 2.77507 | 0.81776 | 1.96651 | 1.2084 | 0.41585 |
| 110 | 1.91986 | 0.42642 | 1.63830 | 0.4901 | 0.26028 | 160 | 2.79253 | 0.82635 | 1.96962 | 1.2253 | 0.41955 |
| 111 | 1.93732 | 0.43359 | 1.64825 | 0.5019 | 0.26306 | 161 | 2.80998 | 0.83495 | 1.97257 | 1.2422 | 0.42328 |
| 112 | 1.95477 | 0.44081 | 1.65808 | 0.5138 | 0.26585 | 162 | 2.82743 | 0.84357 | 1.97538 | 1.2592 | 0.42704 |
| 113 | 1.97222 | 0.44806 | 1.66777 | 0.5259 | 0.26866 | 163 | 2.84489 | 0.85219 | 1.97803 | 1.2763 | 0.43083 |
| 114 | 1.98968 | 0.45536 | 1.67734 | 0.5381 | 0.27148 | 164 | 2.86234 | 0.86083 | 1.98054 | 1.2934 | 0.43464 |
| 115 | 2.00713 | 0.46270 | 1.68678 | 0.5504 | 0.27431 | 165 | 2.87979 | 0.86947 | 1.98289 | 1.3105 | 0.43849 |
| 116 | 2.02458 | 0.47008 | 1.69610 | 0.5629 | 0.27715 | 166 | 2.89725 | 0.87813 | 1.98509 | 1.3277 | 0.44236 |
| 117 | 2.04204 | 0.47750 | 1.70528 | 0.5755 | 0.28001 | 167 | 2.91470 | 0.88680 | 1.98714 | 1.3449 | 0.44627 |
| 118 | 2.05949 | 0.48496 | 1.71433 | 0.5883 | 0.28289 | 168 | 2.93215 | 0.89547 | 1.98904 | 1.3621 | 0.45020 |
| 119 | 2.07694 | 0.49246 | 1.72326 | 0.6012 | 0.28577 | 169 | 2.94961 | 0.90415 | 1.99079 | 1.3794 | 0.45417 |
| 120 | 2.09440 | 0.50000 | 1.73205 | 0.6142 | 0.28868 | 170 | 2.96706 | 0.91284 | 1.99239 | 1.3967 | 0.45817 |
| 121 | 2.11185 | 0.50758 | 1.74071 | 0.6273 | 0.29159 | 171 | 2.98451 | 0.92154 | 1.99383 | 1.4140 | 0.46220 |
| 122 | 2.12930 | 0.51519 | 1.74924 | 0.6406 | 0.29452 | 172 | 3.00197 | 0.93024 | 1.99513 | 1.4314 | 0.46626 |
| 123 | 2.14675 | 0.52284 | 1.75763 | 0.6540 | 0.29747 | 173 | 3.01942 | 0.93895 | 1.99627 | 1.4488 | 0.47035 |
| 124 | 2.16421 | 0.53053 | 1.76590 | 0.6676 | 0.30043 | 174 | 3.03687 | 0.94766 | 1.99726 | 1.4662 | 0.47448 |
| 125 | 2.18166 | 0.53825 | 1.77402 | 0.6813 | 0.30341 | 175 | 3.05433 | 0.95638 | 1.99810 | 1.4836 | 0.47865 |
| 126 | 2.19911 | 0.54601 | 1.78201 | 0.6950 | 0.30640 | 176 | 3.07178 | 0.96510 | 1.99878 | 1.5010 | 0.48284 |
| 127 | 2.21657 | 0.55380 | 1.78987 | 0.7090 | 0.30941 | 177 | 3.08923 | 0.97382 | 1.99931 | 1.5184 | 0.48708 |
| 128 | 2.23402 | 0.56163 | 1.79759 | 0.7230 | 0.31243 | 178 | 3.10669 | 0.98255 | 1.99970 | 1.5359 | 0.49135 |
| 129 | 2.25147 | 0.56949 | 1.80517 | 0.7372 | 0.31548 | 179 | 3.12414 | 0.99127 | 1.99992 | 1.5533 | 0.49566 |
| 130 | 2.26893 | 0.57738 | 1.81262 | 0.7514 | 0.31854 | 180 | 3.14159 | 1.00000 | 2.00000 | 1.5708 | 0.50000 |

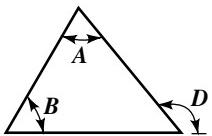
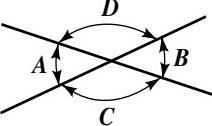
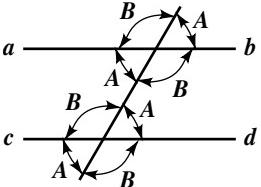
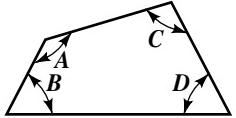
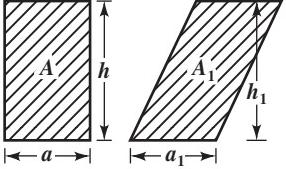
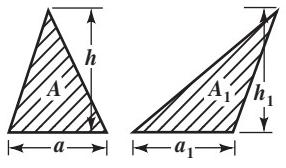
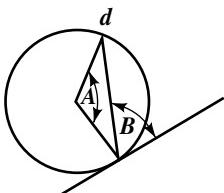
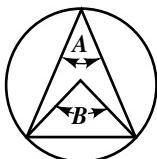
Geometrical Propositions

| | |
|---|---|
|  | <p>The sum of the three angles in a triangle always equals 180 degrees. Hence, if two angles are known, the third angle can always be found.</p> $A + B + C = 180^\circ \quad A = 180^\circ - (B + C)$ $B = 180^\circ - (A + C) \quad C = 180^\circ - (A + B)$ |
|  | <p>If one side and two angles in one triangle are equal to one side and similarly located angles in another triangle, then the remaining two sides and angle also are equal.</p> <p>If $a = a_1$, $A = A_1$, and $B = B_1$, then the two other sides and the remaining angle also are equal.</p> |
|  | <p>If two sides and the angle between them in one triangle are equal to two sides and a similarly located angle in another triangle, then the remaining side and angles also are equal.</p> <p>If $a = a_1$, $b = b_1$, and $A = A_1$, then the remaining side and angles also are equal.</p> |
|  | <p>If the three sides in one triangle are equal to the three sides of another triangle, then the angles in the two triangles also are equal.</p> <p>If $a = a_1$, $b = b_1$, and $c = c_1$, then the angles between the respective sides also are equal.</p> |
|  | <p>If the three sides of one triangle are proportional to corresponding sides in another triangle, then the triangles are called <i>similar</i>, and the angles in the one are equal to the angles in the other.</p> <p>If $a : b : c = d : e : f$, then $A = D$, $B = E$, and $C = F$.</p> |
|  | <p>If the angles in one triangle are equal to the angles in another triangle, then the triangles are similar and their corresponding sides are proportional.</p> <p>If $A = D$, $B = E$, and $C = F$, then $a : b : c = d : e : f$.</p> |
|  | <p>If the three sides in a triangle are equal—that is, if the triangle is <i>equilateral</i>—then the three angles also are equal.</p> <p>Each of the three equal angles in an equilateral triangle is 60 degrees.</p> <p>If the three angles in a triangle are equal, then the three sides also are equal.</p> |

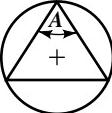
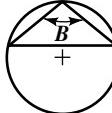
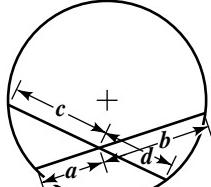
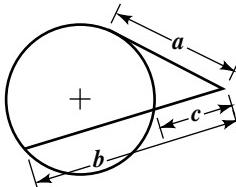
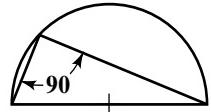
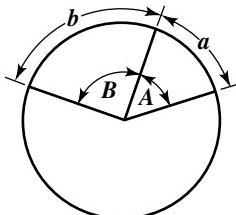
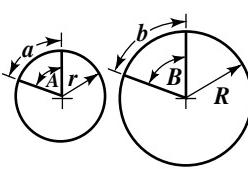
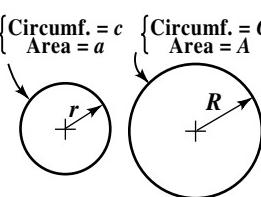
Geometrical Propositions

| | |
|--|--|
| | <p>A line in an equilateral triangle that bisects or divides any of the angles into two equal parts also bisects the side opposite the angle and is at right angles to it.</p> <p>If line AB divides angle CAD into two equal parts, it also divides line CD into two equal parts and is at right angles to it.</p> |
| | <p>If two sides in a triangle are equal—that is, if the triangle is an <i>isosceles</i> triangle—then the angles opposite these sides also are equal.</p> <p>If side a equals side b, then angle A equals angle B.</p> |
| | <p>If two angles in a triangle are equal, the sides opposite these angles also are equal.</p> <p>If angles A and B are equal, then side a equals side b.</p> |
| | <p>In an isosceles triangle, if a straight line is drawn from the point where the two equal sides meet, so that it bisects the third side or base of the triangle, then it also bisects the angle between the equal sides and is perpendicular to the base.</p> |
| | <p>In every triangle, that angle is greater than is opposite a longer side. In every triangle, that side is greater which is opposite a greater angle.</p> <p>If a is longer than b, then angle A is greater than B. If angle A is greater than B, then side a is longer than b.</p> |
| | <p>In every triangle, the sum of the lengths of two sides is always greater than the length of the third.</p> <p>Side $a +$ side b is always greater than side c.</p> |
| | <p>In a right-angle triangle, the square of the hypotenuse or the side opposite the right angle is equal to the sum of the squares on the two sides that form the right angle.</p> $a^2 = b^2 + c^2$ |

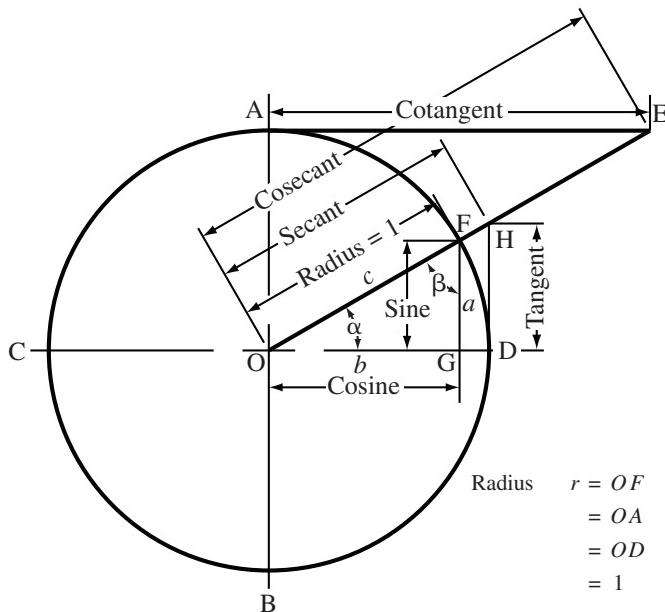
Geometrical Propositions

| | |
|---|--|
|  | <p>If one side of a triangle is produced, then the exterior angle is equal to the sum of the two interior opposite angles.</p> $\text{Angle } D = \text{angle } A + \text{angle } B$ |
|  | <p>If two lines intersect, then the opposite angles formed by the intersecting lines are equal.</p> $\text{Angle } A = \text{angle } B$ $\text{Angle } C = \text{angle } D$ |
|  | <p>If a line intersects two parallel lines, then the corresponding angles formed by the intersecting line and the parallel lines are equal.</p> <p>Lines ab and cd are parallel. Then all the angles designated A are equal, and all those designated B are equal.</p> |
|  | <p>In any figure having four sides, the sum of the interior angles equals 360 degrees.</p> $A + B + C + D = 360 \text{ degrees}$ |
|  | <p>The areas of two parallelograms that have equal base and equal height are equal.</p> <p>If $a = a_1$ and $h = h_1$, then</p> $\text{Area } A = \text{area } A_1$ |
|  | <p>The areas of triangles having equal base and equal height are equal.</p> <p>If $a = a_1$ and $h = h_1$, then</p> $\text{Area } A = \text{area } A_1$ |
|  | <p>The angle between a tangent and a chord drawn from the point of tangency equals one-half the angle at the center subtended by the chord.</p> $\text{Angle } B = \frac{1}{2} \text{ angle } A$ |
|  | <p>If an angle at the circumference of a circle, between two chords, is subtended by the same arc as the angle at the center, between two radii, then the angle at the circumference is equal to one-half of the angle at the center.</p> $\text{Angle } A = \frac{1}{2} \text{ angle } B$ |

Geometrical Propositions

| | |
|--|--|
| A = Less than 90  B = More than 90  | <p>An angle subtended by a chord in a circular segment larger than one-half the circle is an acute angle—an angle less than 90 degrees. An angle subtended by a chord in a circular segment less than one-half the circle is an obtuse angle—an angle greater than 90 degrees.</p> |
|  | <p>If two chords intersect each other in a circle, then the rectangle of the segments of the one equals the rectangle of the segments of the other.</p> $a \times b = c \times d$ |
|  | <p>If from a point outside a circle two lines are drawn, one of which intersects the circle and the other is tangent to it, then the rectangle contained by the total length of the intersecting line, and that part of it that is between the outside point and the periphery, equals the square of the tangent.</p> $a^2 = b \times c$ |
|  | <p>If a triangle is inscribed in a semicircle, the angle opposite the diameter is a right (90-degree) angle.</p> <p>All angles at the periphery of a circle, subtended by the diameter, are right (90-degree) angles.</p> |
|  | <p>The lengths of circular arcs of the same circle are proportional to the corresponding angles at the center.</p> $A : B = a : b$ |
|  | <p>The lengths of circular arcs having the same center angle are proportional to the lengths of the radii.</p> <p>If $A = B$, then $a : b = r : R$.</p> |
| $\left\{ \begin{array}{l} \text{Circumf.} = c \\ \text{Area} = a \end{array} \right.$  | <p>The circumferences of two circles are proportional to their radii.</p> <p>The areas of two circles are proportional to the squares of their radii.</p> $c : C = r : R$ $a : A = r^2 : R^2$ |

Useful Trigonometric Relationships

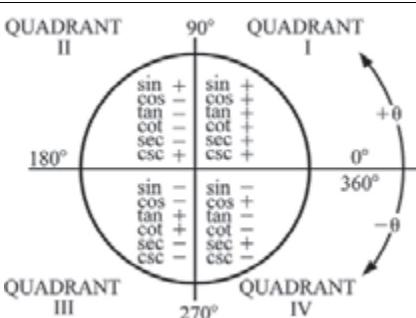


The following formulas will provide the solutions for most triangular problems

In the right angle triangle FOG, $\overline{OF} = c$, $\overline{FG} = a$, and $\overline{OG} = b$

| | | |
|---|--|-----------------------------|
| $\text{arc FD} = \text{Angle } \alpha \times \overline{OD}$ | $\sin \alpha = \frac{a}{c} = \cos \beta$ | $c = \frac{a}{\sin \alpha}$ |
| $\sin \alpha = \overline{FG}$ | $\cos \alpha = \frac{b}{c} = \sin \beta$ | $a = \sin \alpha \times c$ |
| $\cos \alpha = \overline{OG}$ | $\tan \alpha = \frac{a}{b} = \cot \beta$ | $b = \cos \alpha \times c$ |
| $\tan \alpha = \overline{DH}$ | $\cot \alpha = \frac{b}{a} = \tan \beta$ | $a = \tan \alpha \times b$ |
| $\cot \alpha = \overline{AE}$ | $\sec \alpha = \frac{c}{b} = \csc \beta$ | $b = \cot \alpha \times a$ |
| $\csc \alpha = \overline{OE}$ | $\csc \alpha = \frac{c}{a} = \sec \beta$ | $a = \frac{b}{\cot \alpha}$ |
| $\sec \alpha = \overline{OH}$ | | $b = \frac{c}{\sec \alpha}$ |
| Chord $\alpha = \overline{FD}$ | | $a = \frac{c}{\csc \alpha}$ |

Signs of Trigonometric Functions



This diagram shows the proper sign (+ or -) for the trigonometric functions of angles in each of the four quadrants of a complete circle.

Examples: The sine of 226° is -0.71934 ; of 326° , -0.55919 .

Useful Relationships Among Angles

| Angle Function | θ | $-\theta$ | $90^\circ \pm \theta$ | $180^\circ \pm \theta$ | $270^\circ \pm \theta$ | $360^\circ \pm \theta$ |
|----------------|--------------|---------------|-----------------------|------------------------|------------------------|------------------------|
| sin | sin θ | -sin θ | +cos θ | \mp sin θ | -cos θ | \pm sin θ |
| cos | cos θ | +cos θ | \mp sin θ | -cos θ | \pm sin θ | +cos θ |
| tan | tan θ | -tan θ | \mp cot θ | \pm tan θ | \mp cot θ | \pm tan θ |
| cot | cot θ | -cot θ | \mp tan θ | \pm cot θ | \mp tan θ | \pm cot θ |
| sec | sec θ | +sec θ | \mp csc θ | -sec θ | \pm csc θ | +sec θ |
| csc | csc θ | -csc θ | +sec θ | \mp csc θ | -sec θ | \pm csc θ |

Examples: $\cos(270^\circ - \theta) = -\sin \theta$; $\tan(90^\circ + \theta) = -\cot \theta$.

The Law of Sines.— In any triangle, any side is to the sine of the angle opposite that side as any other side is to the sine of the angle opposite that side. If a , b , and c are the sides, and A , B , and C their opposite angles, respectively, then:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}, \quad \text{so that:}$$

$$a = \frac{b \sin A}{\sin B} \quad \text{or} \quad a = \frac{c \sin A}{\sin C}$$

$$b = \frac{a \sin B}{\sin A} \quad \text{or} \quad b = \frac{c \sin B}{\sin C}$$

$$c = \frac{a \sin C}{\sin A} \quad \text{or} \quad c = \frac{b \sin C}{\sin B}$$

The Law of Cosines.— In any triangle, the square of any side is equal to the sum of the squares of the other two sides minus twice their product times the cosine of the included angle; or if a , b and c are the sides and A , B , and C are the opposite angles, respectively, then:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

These two laws, together with the proposition that the sum of the three angles equals 180 degrees, are the basis of all formulas relating to the solution of triangles.

Formulas for the solution of right-angled and oblique-angled triangles, arranged in tabular form, are given on the following pages.

Signs of Trigonometric Functions.— On page 10, a diagram, *Signs of Trigonometric Functions* is given. This diagram shows the proper sign (+ or -) for the trigonometric functions of angles in each of the four quadrants, 0 to 90, 90 to 180, 180 to 270, and 270 to 360 degrees. Thus, the cosine of an angle between 90 and 180 degrees is negative; the sine of the same angle is positive.

Trigonometric Identities.— Trigonometric identities are formulas that show the relationship between different trigonometric functions. They may be used to change the form of some trigonometric expressions to simplify calculations. For example, if a formula has a term, $2 \sin A \cos A$, the equivalent but simpler term $\sin 2A$ may be substituted. The identities that follow may themselves be combined or rearranged in various ways to form new identities.

Basic

$$\tan A = \frac{\sin A}{\cos A} = \frac{1}{\cot A} \quad \sec A = \frac{1}{\cos A} \quad \csc A = \frac{1}{\sin A}$$

Negative Angle

$$\sin(-A) = -\sin A \quad \cos(-A) = \cos A \quad \tan(-A) = -\tan A$$

Pythagorean

$$\sin^2 A + \cos^2 A = 1 \quad 1 + \tan^2 A = \sec^2 A \quad 1 + \cot^2 A = \csc^2 A$$

Sum and Difference of Angles

$$\tan(A + B) = \frac{\tan A + \tan B}{1 - \tan A \tan B} \quad \tan(A - B) = \frac{\tan A - \tan B}{1 + \tan A \tan B}$$

$$\cot(A + B) = \frac{\cot A \cot B - 1}{\cot B + \cot A} \quad \cot(A - B) = \frac{\cot A \cot B + 1}{\cot B - \cot A}$$

$$\sin(A + B) = \sin A \cos B + \cos A \sin B \quad \sin(A - B) = \sin A \cos B - \cos A \sin B$$

$$\cos(A + B) = \cos A \cos B - \sin A \sin B \quad \cos(A - B) = \cos A \cos B + \sin A \sin B$$

Double-Angle

$$\cos 2A = \cos^2 A - \sin^2 A = 2 \cos^2 A - 1 = 1 - 2 \sin^2 A \quad \sin 2A = 2 \sin A \cos A$$

$$\tan 2A = \frac{2 \tan A}{1 - \tan^2 A} = \frac{2}{\cot A - \tan A}$$

Half-Angle

$$\sin \frac{1}{2}A = \sqrt{\frac{1}{2}(1 - \cos A)} \quad \cos \frac{1}{2}A = \sqrt{\frac{1}{2}(1 + \cos A)}$$

$$\tan \frac{1}{2}A = \frac{\sqrt{1 - \cos A}}{\sqrt{1 + \cos A}} = \frac{1 - \cos A}{\sin A} = \frac{\sin A}{1 + \cos A}$$

Product-to-Sum

$$\sin A \cos B = \frac{1}{2}[\sin(A + B) + \sin(A - B)]$$

$$\cos A \cos B = \frac{1}{2}[\cos(A + B) + \cos(A - B)]$$

$$\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)] \quad \tan A \tan B = \frac{\tan A + \tan B}{\cot A + \cot B}$$

Sum and Difference of Functions

$$\sin A + \sin B = 2[\sin \frac{1}{2}(A + B) \cos \frac{1}{2}(A - B)]$$

$$\sin A - \sin B = 2[\sin \frac{1}{2}(A - B) \cos \frac{1}{2}(A + B)]$$

$$\cos A + \cos B = 2[\cos \frac{1}{2}(A + B) \cos \frac{1}{2}(A - B)]$$

$$\cos A - \cos B = -2[\sin \frac{1}{2}(A + B) \sin \frac{1}{2}(A - B)]$$

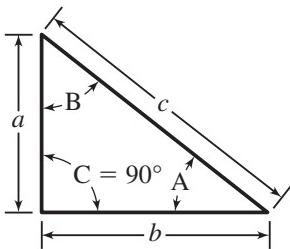
$$\tan A + \tan B = \frac{\sin(A + B)}{\cos A \cos B} \quad \tan A - \tan B = \frac{\sin(A - B)}{\cos A \cos B}$$

$$\cot A + \cot B = \frac{\sin(B + A)}{\sin A \sin B} \quad \cot A - \cot B = \frac{\sin(B - A)}{\sin A \sin B}$$

Chart For The Rapid Solution of Right-Angle and Oblique-Angle Triangles

| | | | |
|--|--|--------------------------------------|--|
| $C = \sqrt{A^2 - B^2}$ | $\sin d = \frac{B}{A}$ | $e = 90^\circ - d$ | $B = \sqrt{A^2 - C^2}$ |
| | | | |
| $\sin e = \frac{C}{A}$ | $d = 90^\circ - e$ | $A = \sqrt{B^2 + C^2}$ | $\tan d = \frac{B}{C}$ |
| | | | |
| $B = A \times \sin d$ | $C = A \times \cos d$ | $B = A \times \cos e$ | $C = A \times \sin e$ |
| | | | |
| $A = \frac{B}{\sin d}$ | $C = B \times \cot d$ | $A = \frac{B}{\cos e}$ | $C = B \times \tan e$ |
| | | | |
| $A = \frac{C}{\cos d}$ | $B = \frac{C}{\cot d}$ | $A = \frac{C}{\sin e}$ | $B = C \times \cote$ |
| | | | |
| $B = \frac{A \times \sin f}{\sin d}$ | $e = 180^\circ - (d+f)$ | $C = \frac{A \times \sin e}{\sin d}$ | $\tan d = \frac{A \times \sin e}{B - A \times \cos e}$ |
| | | | |
| $f = 180^\circ - (d+e)$ | $C = \frac{A \times \sin e}{\sin d}$ | $\sin f = \frac{B \times \sin d}{A}$ | $e = 180^\circ - (d+f)$ |
| | | | |
| $\text{Area} = \frac{A \times B \times \sin e}{2}$ | $\cos d = \frac{B^2 + C^2 - A^2}{2 \times B \times C}$ | $\sin f = \frac{B \times \sin d}{A}$ | $e = 180^\circ - (d+f)$ |
| | | | |

Solution of Right-Angled Triangles

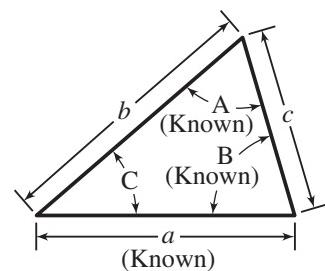


As shown in the illustration, the sides of the right-angled triangle are designated a and b and the hypotenuse, c . The angles opposite each of these sides are designated A and B , respectively.

Angle C , opposite the hypotenuse c is the right angle, and is therefore always one of the known quantities.

| Sides and Angles Known | Formulas for Sides and Angles to be Found | | | Area |
|-----------------------------|---|------------------------|--------------------|---------------------------------------|
| Side a side b | $c = \sqrt{a^2 + b^2}$ | $\tan A = \frac{a}{b}$ | $B = 90^\circ - A$ | $\frac{a \times b}{2}$ |
| Side a hypotenuse c | $b = \sqrt{c^2 - a^2}$ | $\sin A = \frac{a}{c}$ | $B = 90^\circ - A$ | $\frac{a \times \sqrt{c^2 - a^2}}{2}$ |
| Side b hypotenuse c | $a = \sqrt{c^2 - b^2}$ | $\sin B = \frac{b}{c}$ | $A = 90^\circ - B$ | $\frac{b \times \sqrt{c^2 - b^2}}{2}$ |
| Hypotenuse c angle B | $b = c \times \sin B$ | $a = c \times \cos B$ | $A = 90^\circ - B$ | $c^2 \times \sin B \times \cos B$ |
| Hypotenuse c angle A | $b = c \times \cos A$ | $a = c \times \sin A$ | $B = 90^\circ - A$ | $c^2 \times \sin A \times \cos A$ |
| Side b angle B | $c = \frac{b}{\sin B}$ | $a = b \times \cot B$ | $A = 90^\circ - B$ | $\frac{b^2}{2 \times \tan B}$ |
| Side b angle A | $c = \frac{b}{\cos A}$ | $a = b \times \tan A$ | $B = 90^\circ - A$ | $\frac{b^2 \times \tan A}{2}$ |
| Side a angle B | $c = \frac{a}{\cos B}$ | $b = a \times \tan B$ | $A = 90^\circ - B$ | $\frac{a^2 \times \tan B}{2}$ |
| Side a angle A | $c = \frac{a}{\sin A}$ | $b = a \times \cot A$ | $B = 90^\circ - A$ | $\frac{a^2}{2 \times \tan A}$ |

Solution of Oblique-Angled Triangles



One side and two angles known

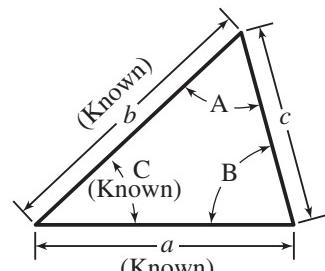
Call the known side a , the angle opposite it A , and the other known angle B . Then:

$C = 180^\circ - (A + B)$; or if angles B and C are given, but not A , then $A = 180^\circ - (B + C)$.

$$C = 180^\circ - (A + B)$$

$$b = \frac{a \times \sin B}{\sin A} \quad c = \frac{a \times \sin C}{\sin A}$$

$$\text{Area} = \frac{a \times b \times \sin C}{2}$$



Two sides and the angle between them known

Call the known sides a and b , and the known angle between them C . Then:

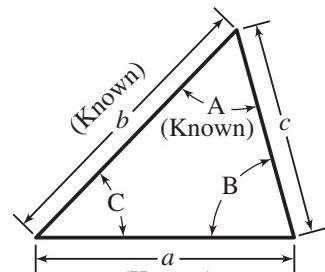
$$\tan A = \frac{a \times \sin C}{b - (a \times \cos C)}$$

$$B = 180^\circ - (A + C) \quad c = \frac{a \times \sin C}{\sin A}$$

Side c may also be found directly as below:

$$c = \sqrt{a^2 + b^2 - (2ab \times \cos C)}$$

$$\text{Area} = \frac{a \times b \times \sin C}{2}$$



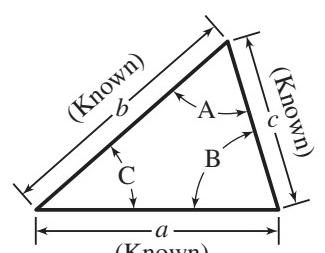
Two sides and the angle opposite one of the sides known

Call the known angle A , the side opposite it a , and the other known side b . Then:

$$\sin B = \frac{b \times \sin A}{a} \quad C = 180^\circ - (A + B)$$

$$c = \frac{a \times \sin C}{\sin A} \quad \text{Area} = \frac{a \times b \times \sin C}{2}$$

If, in the above, angle $B > \text{angle } A$ but $< 90^\circ$, then a second solution B_2, C_2, c_2 exists for which: $B_2 = 180^\circ - B$; $C_2 = 180^\circ - (A + B_2)$; $c_2 = (a \times \sin C_2) / \sin A$; area = $(a \times b \times \sin C_2) / 2$. If $a \geq b$, then the first solution only exists. If $a < b \times \sin A$, then no solution exists.



All three sides known

Call the sides a, b , and c , and the angles opposite them, A, B , and C . Then:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \quad \sin B = \frac{b \times \sin A}{a}$$

$$C = 180^\circ - (A + B) \quad \text{Area} = \frac{a \times b \times \sin C}{2}$$

Trigonometric Functions of Angles from 0° to 15° and 75° to 90°

| Angle | sin | cos | tan | cot | | Angle | sin | cos | tan | cot | |
|---------------|----------|----------|----------|----------|----------------|---------------|----------|----------|----------|----------|----------------|
| | cos | sin | cot | tan | | Angle | cos | sin | cot | tan | Angle |
| $0^\circ 0'$ | 0.000000 | 1.000000 | 0.000000 | — | $90^\circ 0'$ | $7^\circ 30'$ | 0.130526 | 0.991445 | 0.131652 | 7.595754 | $82^\circ 30'$ |
| 10 | 0.002909 | 0.999996 | 0.002909 | 343.7737 | 50 | 40 | 0.133410 | 0.991061 | 0.134613 | 7.428706 | 20 |
| 20 | 0.005818 | 0.999983 | 0.005818 | 171.8854 | 40 | 50 | 0.136292 | 0.990669 | 0.137576 | 7.268725 | 10 |
| 30 | 0.008727 | 0.999962 | 0.008727 | 114.5887 | 30 | $8^\circ 0'$ | 0.139173 | 0.990268 | 0.140541 | 7.115370 | $82^\circ 0'$ |
| 40 | 0.011635 | 0.999932 | 0.011636 | 85.93979 | 20 | 10 | 0.142053 | 0.989859 | 0.143508 | 6.968234 | 50 |
| 50 | 0.014544 | 0.999894 | 0.014545 | 68.75009 | 10 | 20 | 0.144932 | 0.989442 | 0.146478 | 6.826944 | 40 |
| $1^\circ 0'$ | 0.017452 | 0.999848 | 0.017455 | 57.28996 | $89^\circ 0'$ | 30 | 0.147809 | 0.989016 | 0.149451 | 6.691156 | 30 |
| 10 | 0.020361 | 0.999793 | 0.020365 | 49.10388 | 50 | 40 | 0.150686 | 0.988582 | 0.152426 | 6.560554 | 20 |
| 20 | 0.023269 | 0.999729 | 0.023275 | 42.96408 | 40 | 50 | 0.153561 | 0.988139 | 0.155404 | 6.434843 | 10 |
| 30 | 0.026177 | 0.999657 | 0.026186 | 38.18846 | 30 | $9^\circ 0'$ | 0.156434 | 0.987688 | 0.158384 | 6.313752 | $81^\circ 0'$ |
| 40 | 0.029085 | 0.999577 | 0.029097 | 34.36777 | 20 | 10 | 0.159307 | 0.987229 | 0.161368 | 6.197028 | 50 |
| 50 | 0.031992 | 0.999488 | 0.032009 | 31.24158 | 10 | 20 | 0.162178 | 0.986762 | 0.164354 | 6.084438 | 40 |
| $2^\circ 0'$ | 0.034899 | 0.999391 | 0.034921 | 28.63625 | $88^\circ 0'$ | 30 | 0.165048 | 0.986286 | 0.167343 | 5.975764 | 30 |
| 10 | 0.037806 | 0.999285 | 0.037834 | 26.43160 | 50 | 40 | 0.167916 | 0.985801 | 0.170334 | 5.870804 | 20 |
| 20 | 0.040713 | 0.999171 | 0.040747 | 24.54176 | 40 | 50 | 0.170783 | 0.985309 | 0.173329 | 5.769369 | 10 |
| 30 | 0.043619 | 0.999048 | 0.043661 | 22.90377 | 30 | $10^\circ 0'$ | 0.173648 | 0.984808 | 0.176327 | 5.671282 | $80^\circ 0'$ |
| 40 | 0.046525 | 0.998917 | 0.046576 | 21.47040 | 20 | 10 | 0.176512 | 0.984298 | 0.179328 | 5.576379 | 50 |
| 50 | 0.049431 | 0.998778 | 0.049491 | 20.20555 | 10 | 20 | 0.179375 | 0.983781 | 0.182332 | 5.484505 | 40 |
| $3^\circ 0'$ | 0.052336 | 0.998630 | 0.052408 | 19.08114 | $87^\circ 0'$ | 30 | 0.182236 | 0.983255 | 0.185339 | 5.395517 | 30 |
| 10 | 0.055241 | 0.998473 | 0.055325 | 18.07498 | 50 | 40 | 0.185095 | 0.982721 | 0.188349 | 5.309279 | 20 |
| 20 | 0.058145 | 0.998308 | 0.058243 | 17.16934 | 40 | 50 | 0.187953 | 0.982178 | 0.191363 | 5.225665 | 10 |
| 30 | 0.061049 | 0.998135 | 0.061163 | 16.34986 | 30 | $11^\circ 0'$ | 0.190809 | 0.981627 | 0.194380 | 5.144554 | $79^\circ 0'$ |
| 40 | 0.063952 | 0.997953 | 0.064083 | 15.60478 | 20 | 10 | 0.193664 | 0.981068 | 0.197401 | 5.065835 | 50 |
| 50 | 0.066854 | 0.997763 | 0.067004 | 14.92442 | 10 | 20 | 0.196517 | 0.980500 | 0.200425 | 4.989403 | 40 |
| $4^\circ 0'$ | 0.069756 | 0.997564 | 0.069927 | 14.30067 | $86^\circ 0'$ | 30 | 0.199368 | 0.979925 | 0.203452 | 4.915157 | 30 |
| 10 | 0.072658 | 0.997357 | 0.072851 | 13.72674 | 50 | 40 | 0.202218 | 0.979341 | 0.206483 | 4.843005 | 20 |
| 20 | 0.075559 | 0.997141 | 0.075775 | 13.19688 | 40 | 50 | 0.205065 | 0.978748 | 0.209518 | 4.772857 | 10 |
| 30 | 0.078459 | 0.996917 | 0.078702 | 12.70621 | 30 | $12^\circ 0'$ | 0.207912 | 0.978148 | 0.212557 | 4.704630 | $78^\circ 0'$ |
| 40 | 0.081359 | 0.996685 | 0.081629 | 12.25051 | 20 | 10 | 0.210756 | 0.977539 | 0.215599 | 4.638246 | 50 |
| 50 | 0.084258 | 0.996444 | 0.084558 | 11.82617 | 10 | 20 | 0.213599 | 0.976921 | 0.218645 | 4.573629 | 40 |
| $5^\circ 0'$ | 0.087156 | 0.996195 | 0.087489 | 11.43005 | $85^\circ 0'$ | 30 | 0.216440 | 0.976296 | 0.221695 | 4.510709 | 30 |
| 10 | 0.090053 | 0.995937 | 0.090421 | 11.05943 | 50 | 40 | 0.219279 | 0.975662 | 0.224748 | 4.449418 | 20 |
| 20 | 0.092950 | 0.995671 | 0.093354 | 10.71191 | 40 | 50 | 0.222116 | 0.975020 | 0.227806 | 4.389694 | 10 |
| 30 | 0.095846 | 0.995396 | 0.096289 | 10.38540 | 30 | $13^\circ 0'$ | 0.224951 | 0.974370 | 0.230868 | 4.331476 | $77^\circ 0'$ |
| 40 | 0.098741 | 0.995113 | 0.099226 | 10.07803 | 20 | 10 | 0.227784 | 0.973712 | 0.233934 | 4.274707 | 50 |
| 50 | 0.101635 | 0.994822 | 0.102164 | 9.788173 | 10 | 20 | 0.230616 | 0.973045 | 0.237004 | 4.219332 | 40 |
| $6^\circ 0'$ | 0.104528 | 0.994522 | 0.105104 | 9.514364 | $84^\circ 0'$ | 30 | 0.233445 | 0.972370 | 0.240079 | 4.165300 | 30 |
| 10 | 0.107421 | 0.994214 | 0.108046 | 9.255304 | 50 | 40 | 0.236273 | 0.971687 | 0.243157 | 4.112561 | 20 |
| 20 | 0.110313 | 0.993897 | 0.110990 | 9.009826 | 40 | 50 | 0.239098 | 0.970995 | 0.246241 | 4.061070 | 10 |
| 30 | 0.113203 | 0.993572 | 0.113936 | 8.776887 | 30 | $14^\circ 0'$ | 0.241922 | 0.970296 | 0.249328 | 4.010781 | $76^\circ 0'$ |
| 40 | 0.116093 | 0.993238 | 0.116883 | 8.555547 | 20 | 10 | 0.244743 | 0.969588 | 0.252420 | 3.961652 | 50 |
| 50 | 0.118982 | 0.992896 | 0.119833 | 8.344956 | 10 | 20 | 0.247563 | 0.968872 | 0.255516 | 3.913642 | 40 |
| $7^\circ 0'$ | 0.121869 | 0.992546 | 0.122785 | 8.144346 | $83^\circ 0'$ | 30 | 0.250380 | 0.968148 | 0.258618 | 3.866713 | 30 |
| 10 | 0.124756 | 0.992187 | 0.125738 | 7.953022 | 50 | 40 | 0.253195 | 0.967415 | 0.261723 | 3.820828 | 20 |
| 20 | 0.127642 | 0.991820 | 0.128694 | 7.770351 | 40 | 50 | 0.256008 | 0.966675 | 0.264834 | 3.775952 | 10 |
| $7^\circ 30'$ | 0.130526 | 0.991445 | 0.131652 | 7.595754 | $82^\circ 30'$ | $15^\circ 0'$ | 0.258819 | 0.965926 | 0.267949 | 3.732051 | $75^\circ 0'$ |
| | cos | sin | cot | tan | | Angle | cos | sin | cot | tan | Angle |

For angles 0° to $15^\circ 0'$ (angles found in a column to the left of the data), use the column labels at the top of the table; for angles 75° to $90^\circ 0'$ (angles found in a column to the right of the data), use the column labels at the bottom of the table.

Trigonometric Functions of Angles from 15° to 30° and 60° to 75°

| Angle | sin | cos | tan | cot | | Angle | sin | cos | tan | cot | |
|----------------|----------|----------|----------|----------|----------------|----------------|----------|----------|----------|----------|---------------|
| | cos | sin | cot | tan | Angle | | cos | sin | cot | tan | Angle |
| $15^\circ 0'$ | 0.258819 | 0.965926 | 0.267949 | 3.732051 | $75^\circ 0'$ | $22^\circ 30'$ | 0.382683 | 0.923880 | 0.414214 | 2.414214 | $67^\circ 30$ |
| 10 | 0.261628 | 0.965169 | 0.271069 | 3.689093 | 50 | 40 | 0.385369 | 0.922762 | 0.417626 | 2.394489 | 20 |
| 20 | 0.264434 | 0.964404 | 0.274194 | 3.647047 | 40 | 50 | 0.388052 | 0.921638 | 0.421046 | 2.375037 | 10 |
| 30 | 0.267238 | 0.963630 | 0.277325 | 3.605884 | 30 | $23^\circ 0'$ | 0.390731 | 0.920505 | 0.424475 | 2.355852 | $67^\circ 0'$ |
| 40 | 0.270040 | 0.962849 | 0.280460 | 3.565575 | 20 | 10 | 0.393407 | 0.919364 | 0.427912 | 2.336929 | 50 |
| 50 | 0.272840 | 0.962059 | 0.283600 | 3.526094 | 10 | 20 | 0.396080 | 0.918216 | 0.431358 | 2.318261 | 40 |
| $16^\circ 0'$ | 0.275637 | 0.961262 | 0.286745 | 3.487414 | $74^\circ 0'$ | 30 | 0.398749 | 0.917060 | 0.434812 | 2.299843 | 30 |
| 10 | 0.278432 | 0.960456 | 0.289896 | 3.449512 | 50 | 40 | 0.401415 | 0.915896 | 0.438276 | 2.281669 | 20 |
| 20 | 0.281225 | 0.959642 | 0.293052 | 3.412363 | 40 | 50 | 0.404078 | 0.914725 | 0.441748 | 2.263736 | 10 |
| 30 | 0.284015 | 0.958820 | 0.296213 | 3.375943 | 30 | $24^\circ 0'$ | 0.406737 | 0.913545 | 0.445229 | 2.246037 | $66^\circ 0'$ |
| 40 | 0.286803 | 0.957990 | 0.299380 | 3.340233 | 20 | 10 | 0.409392 | 0.912358 | 0.448719 | 2.228568 | 50 |
| 50 | 0.289589 | 0.957151 | 0.302553 | 3.305209 | 10 | 20 | 0.412045 | 0.911164 | 0.452218 | 2.211323 | 40 |
| $17^\circ 0'$ | 0.292372 | 0.956305 | 0.305731 | 3.270853 | $73^\circ 0'$ | 30 | 0.414693 | 0.909961 | 0.455726 | 2.194300 | 30 |
| 10 | 0.295152 | 0.955450 | 0.308914 | 3.237144 | 50 | 40 | 0.417338 | 0.908751 | 0.459244 | 2.177492 | 20 |
| 20 | 0.297930 | 0.954588 | 0.312104 | 3.204064 | 40 | 50 | 0.419980 | 0.907533 | 0.462771 | 2.160896 | 10 |
| 30 | 0.300706 | 0.953717 | 0.315299 | 3.171595 | 30 | $25^\circ 0'$ | 0.422618 | 0.906308 | 0.466308 | 2.144507 | $65^\circ 0'$ |
| 40 | 0.303479 | 0.952838 | 0.318500 | 3.139719 | 20 | 10 | 0.425253 | 0.905075 | 0.469854 | 2.128321 | 50 |
| 50 | 0.306249 | 0.951951 | 0.321707 | 3.108421 | 10 | 20 | 0.427884 | 0.903834 | 0.473410 | 2.112335 | 40 |
| $18^\circ 0'$ | 0.309017 | 0.951057 | 0.324920 | 3.077684 | $72^\circ 0'$ | 30 | 0.430511 | 0.902585 | 0.476976 | 2.096544 | 30 |
| 10 | 0.311782 | 0.950154 | 0.328139 | 3.047492 | 50 | 40 | 0.433135 | 0.901329 | 0.480551 | 2.080944 | 20 |
| 20 | 0.314545 | 0.949243 | 0.331364 | 3.017830 | 40 | 50 | 0.435755 | 0.900065 | 0.484137 | 2.065532 | 10 |
| 30 | 0.317305 | 0.948324 | 0.334595 | 2.988685 | 30 | $26^\circ 0'$ | 0.438371 | 0.898794 | 0.487733 | 2.050304 | $64^\circ 0'$ |
| 40 | 0.320062 | 0.947397 | 0.337833 | 2.960042 | 20 | 10 | 0.440984 | 0.897515 | 0.491339 | 2.035256 | 50 |
| 50 | 0.322816 | 0.946462 | 0.341077 | 2.931888 | 10 | 20 | 0.443593 | 0.896229 | 0.494955 | 2.020386 | 40 |
| $19^\circ 0'$ | 0.325568 | 0.945519 | 0.344328 | 2.904211 | $71^\circ 0'$ | 30 | 0.446198 | 0.894934 | 0.498582 | 2.005690 | 30 |
| 10 | 0.328317 | 0.944568 | 0.347585 | 2.876997 | 50 | 40 | 0.448799 | 0.893633 | 0.502219 | 1.991164 | 20 |
| 20 | 0.331063 | 0.943609 | 0.350848 | 2.850235 | 40 | 50 | 0.451397 | 0.892323 | 0.505867 | 1.976805 | 10 |
| 30 | 0.333807 | 0.942641 | 0.354119 | 2.823913 | 30 | $27^\circ 0'$ | 0.453990 | 0.891007 | 0.509525 | 1.962611 | $63^\circ 0'$ |
| 40 | 0.336547 | 0.941666 | 0.357396 | 2.798020 | 20 | 10 | 0.456580 | 0.889682 | 0.513195 | 1.948577 | 50 |
| 50 | 0.339285 | 0.940684 | 0.360679 | 2.772545 | 10 | 20 | 0.459166 | 0.888350 | 0.516875 | 1.934702 | 40 |
| $20^\circ 0'$ | 0.342020 | 0.939693 | 0.363970 | 2.747477 | $70^\circ 0'$ | 30 | 0.461749 | 0.887011 | 0.520567 | 1.920982 | 30 |
| 10 | 0.344752 | 0.938694 | 0.367268 | 2.722808 | 50 | 40 | 0.464327 | 0.885664 | 0.524270 | 1.907415 | 20 |
| 20 | 0.347481 | 0.937687 | 0.370573 | 2.698525 | 40 | 50 | 0.466901 | 0.884309 | 0.527984 | 1.893997 | 10 |
| 30 | 0.350207 | 0.936672 | 0.373885 | 2.674621 | 30 | $28^\circ 0'$ | 0.469472 | 0.882948 | 0.531709 | 1.880726 | $62^\circ 0'$ |
| 40 | 0.352931 | 0.935650 | 0.377204 | 2.651087 | 20 | 10 | 0.472038 | 0.881578 | 0.535446 | 1.867600 | 50 |
| 50 | 0.355651 | 0.934619 | 0.380530 | 2.627912 | 10 | 20 | 0.474600 | 0.880201 | 0.539195 | 1.854616 | 40 |
| $21^\circ 0'$ | 0.358368 | 0.933580 | 0.383864 | 2.605089 | $69^\circ 0'$ | 30 | 0.477159 | 0.878817 | 0.542956 | 1.841771 | 30 |
| 10 | 0.361082 | 0.932534 | 0.387205 | 2.582609 | 50 | 40 | 0.479713 | 0.877425 | 0.546728 | 1.829063 | 20 |
| 20 | 0.363793 | 0.931480 | 0.390554 | 2.560465 | 40 | 50 | 0.482263 | 0.876026 | 0.550513 | 1.816489 | 10 |
| 30 | 0.366501 | 0.930418 | 0.393910 | 2.538648 | 30 | $29^\circ 0'$ | 0.484810 | 0.874620 | 0.554309 | 1.804048 | $61^\circ 0'$ |
| 40 | 0.369206 | 0.929348 | 0.397275 | 2.517151 | 20 | 10 | 0.487352 | 0.873206 | 0.558118 | 1.791736 | 50 |
| 50 | 0.371908 | 0.928270 | 0.400646 | 2.495966 | 10 | 20 | 0.489890 | 0.871784 | 0.561939 | 1.779552 | 40 |
| $22^\circ 0'$ | 0.374607 | 0.927184 | 0.404026 | 2.475087 | $68^\circ 0'$ | 30 | 0.492424 | 0.870356 | 0.565773 | 1.767494 | 30 |
| 10 | 0.377302 | 0.926090 | 0.407414 | 2.454506 | 50 | 40 | 0.494953 | 0.868920 | 0.569619 | 1.755559 | 20 |
| 20 | 0.379994 | 0.924989 | 0.410810 | 2.434217 | 40 | 50 | 0.497479 | 0.867476 | 0.573478 | 1.743745 | 10 |
| $22^\circ 30'$ | 0.382683 | 0.923880 | 0.414214 | 2.414214 | $67^\circ 30'$ | $30^\circ 0'$ | 0.500000 | 0.866025 | 0.577350 | 1.732051 | $60^\circ 0'$ |
| | cos | sin | cot | tan | Angle | | cos | sin | cot | tan | Angle |

For angles 15° to $30^\circ 0'$ (angles found in a column to the left of the data), use the column labels at the top of the table; for angles 60° to $75^\circ 0'$ (angles found in a column to the right of the data), use the column labels at the bottom of the table.

Trigonometric Functions of Angles from 30° to 60°

| Angle | sin | cos | tan | cot | | Angle | sin | cos | tan | cot | |
|---------------|----------|----------|----------|----------|---------------|----------------|----------|----------|----------|----------|----------------|
| $30^\circ 0'$ | 0.500000 | 0.866025 | 0.577350 | 1.732051 | $60^\circ 0'$ | $37^\circ 30'$ | 0.608761 | 0.793353 | 0.767327 | 1.303225 | $52^\circ 30'$ |
| 10 | 0.502517 | 0.864567 | 0.581235 | 1.720474 | 50 | 40 | 0.611067 | 0.791579 | 0.771959 | 1.295406 | 20 |
| 20 | 0.505030 | 0.863102 | 0.585134 | 1.709012 | 40 | 50 | 0.613367 | 0.789798 | 0.776612 | 1.287645 | 10 |
| 30 | 0.507538 | 0.861629 | 0.589045 | 1.697663 | 30 | 38° 0' | 0.615661 | 0.788011 | 0.781286 | 1.279942 | 52° 0' |
| 40 | 0.510043 | 0.860149 | 0.592970 | 1.686426 | 20 | 10 | 0.617951 | 0.786217 | 0.785981 | 1.272296 | 50 |
| 50 | 0.512543 | 0.858662 | 0.596908 | 1.675299 | 10 | 20 | 0.620235 | 0.784416 | 0.790697 | 1.264706 | 40 |
| 31° 0' | 0.515038 | 0.857167 | 0.600861 | 1.664279 | 59° 0' | 30 | 0.622515 | 0.782608 | 0.795436 | 1.257172 | 30 |
| 10 | 0.517529 | 0.855665 | 0.604827 | 1.653366 | 50 | 40 | 0.624789 | 0.780794 | 0.800196 | 1.249693 | 20 |
| 20 | 0.520016 | 0.854156 | 0.608807 | 1.642558 | 40 | 50 | 0.627057 | 0.778973 | 0.804979 | 1.242268 | 10 |
| 30 | 0.522499 | 0.852640 | 0.612801 | 1.631852 | 30 | 39° 0' | 0.629320 | 0.777146 | 0.809784 | 1.234897 | 51° 0' |
| 40 | 0.524977 | 0.851117 | 0.616809 | 1.621247 | 20 | 10 | 0.631578 | 0.775312 | 0.814612 | 1.227579 | 50 |
| 50 | 0.527450 | 0.849586 | 0.620832 | 1.610742 | 10 | 20 | 0.633831 | 0.773472 | 0.819463 | 1.220312 | 40 |
| 32° 0' | 0.529919 | 0.848048 | 0.624869 | 1.600335 | 58° 0' | 30 | 0.636078 | 0.771625 | 0.824336 | 1.213097 | 30 |
| 10 | 0.532384 | 0.846503 | 0.628921 | 1.590024 | 50 | 40 | 0.638320 | 0.769771 | 0.829234 | 1.205933 | 20 |
| 20 | 0.534844 | 0.844951 | 0.632988 | 1.579808 | 40 | 50 | 0.640557 | 0.767911 | 0.834155 | 1.198818 | 10 |
| 30 | 0.537300 | 0.843391 | 0.637070 | 1.569686 | 30 | 40° 0' | 0.642788 | 0.766044 | 0.839100 | 1.191754 | 50° 0' |
| 40 | 0.539751 | 0.841825 | 0.641167 | 1.559655 | 20 | 10 | 0.645013 | 0.764171 | 0.844069 | 1.184738 | 50 |
| 50 | 0.542197 | 0.840251 | 0.645280 | 1.549715 | 10 | 20 | 0.647233 | 0.762292 | 0.849062 | 1.177770 | 40 |
| 33° 0' | 0.544639 | 0.838671 | 0.649408 | 1.539865 | 57° 0' | 30 | 0.649448 | 0.760406 | 0.854081 | 1.170850 | 30 |
| 10 | 0.547076 | 0.837083 | 0.653551 | 1.530102 | 50 | 40 | 0.651657 | 0.758514 | 0.859124 | 1.163976 | 20 |
| 20 | 0.549509 | 0.835488 | 0.657710 | 1.520426 | 40 | 50 | 0.653861 | 0.756615 | 0.864193 | 1.157149 | 10 |
| 30 | 0.551937 | 0.833886 | 0.661886 | 1.510835 | 30 | 41° 0' | 0.656059 | 0.754710 | 0.869287 | 1.150368 | 49° 0' |
| 40 | 0.554360 | 0.832277 | 0.666077 | 1.501328 | 20 | 10 | 0.658252 | 0.752798 | 0.874407 | 1.143633 | 50 |
| 50 | 0.556779 | 0.830661 | 0.670284 | 1.491904 | 10 | 20 | 0.660439 | 0.750880 | 0.879553 | 1.136941 | 40 |
| 34° 0' | 0.559193 | 0.829038 | 0.674509 | 1.482561 | 56° 0' | 30 | 0.662620 | 0.748956 | 0.884725 | 1.130294 | 30 |
| 10 | 0.561602 | 0.827407 | 0.678749 | 1.473298 | 50 | 40 | 0.664796 | 0.747025 | 0.889924 | 1.123691 | 20 |
| 20 | 0.564007 | 0.825770 | 0.683007 | 1.464115 | 40 | 50 | 0.666966 | 0.745088 | 0.895151 | 1.117130 | 10 |
| 30 | 0.566406 | 0.824126 | 0.687281 | 1.455009 | 30 | 42° 0' | 0.669131 | 0.743145 | 0.900404 | 1.110613 | 48° 0' |
| 40 | 0.568801 | 0.822475 | 0.691572 | 1.445980 | 20 | 10 | 0.671289 | 0.741195 | 0.905685 | 1.104137 | 50 |
| 50 | 0.571191 | 0.820817 | 0.695881 | 1.437027 | 10 | 20 | 0.673443 | 0.739239 | 0.910994 | 1.097702 | 40 |
| 35° 0' | 0.573576 | 0.819152 | 0.700208 | 1.428148 | 55° 0' | 30 | 0.675590 | 0.737277 | 0.916331 | 1.091309 | 30 |
| 10 | 0.575957 | 0.817480 | 0.704551 | 1.419343 | 50 | 40 | 0.677732 | 0.735309 | 0.921697 | 1.084955 | 20 |
| 20 | 0.578332 | 0.815801 | 0.708913 | 1.410610 | 40 | 50 | 0.679868 | 0.733334 | 0.927091 | 1.078642 | 10 |
| 30 | 0.580703 | 0.814116 | 0.713293 | 1.401948 | 30 | 43° 0' | 0.681998 | 0.731354 | 0.932515 | 1.072369 | 47° 0' |
| 40 | 0.583069 | 0.812423 | 0.717691 | 1.393357 | 20 | 10 | 0.684123 | 0.729367 | 0.937968 | 1.066134 | 50 |
| 50 | 0.585429 | 0.810723 | 0.722108 | 1.384835 | 10 | 20 | 0.686242 | 0.727374 | 0.943451 | 1.059938 | 40 |
| 36° 0' | 0.587775 | 0.809017 | 0.726543 | 1.376382 | 54° 0' | 30 | 0.688355 | 0.725374 | 0.948965 | 1.053780 | 30 |
| 10 | 0.590136 | 0.807304 | 0.730996 | 1.367996 | 50 | 40 | 0.690462 | 0.723369 | 0.954508 | 1.047660 | 20 |
| 20 | 0.592482 | 0.805584 | 0.735469 | 1.359676 | 40 | 50 | 0.692563 | 0.721357 | 0.960083 | 1.041577 | 10 |
| 30 | 0.594823 | 0.803857 | 0.739961 | 1.351422 | 30 | 44° 0' | 0.694658 | 0.719340 | 0.965689 | 1.035530 | 46° 0' |
| 40 | 0.597159 | 0.802123 | 0.744472 | 1.343233 | 20 | 10 | 0.696748 | 0.717316 | 0.971326 | 1.029520 | 50 |
| 50 | 0.599489 | 0.800383 | 0.749003 | 1.335108 | 10 | 20 | 0.698832 | 0.715286 | 0.976996 | 1.023546 | 40 |
| 37° 0' | 0.601815 | 0.798636 | 0.753554 | 1.327045 | 53° 0' | 30 | 0.700909 | 0.713250 | 0.982697 | 1.017607 | 30 |
| 10 | 0.604136 | 0.796882 | 0.758125 | 1.319044 | 50 | 40 | 0.702981 | 0.711209 | 0.988432 | 1.011704 | 20 |
| 20 | 0.606451 | 0.795121 | 0.762716 | 1.311105 | 40 | 50 | 0.705047 | 0.709161 | 0.994199 | 1.005835 | 10 |
| 37° 30' | 0.608761 | 0.793353 | 0.767327 | 1.303225 | 52° 30' | 45° 0' | 0.707107 | 0.707107 | 1.000000 | 1.000000 | 45° 0' |
| | cos | sin | cot | tan | Angle | | cos | sin | cot | tan | Angle |

For angles 30° to $45^\circ 0'$ (angles found in a column to the left of the data), use the column labels at the top of the table; for angles 45° to $60^\circ 0'$ (angles found in a column to the right of the data), use the column labels at the bottom of the table.

Formulas for Compound Angles

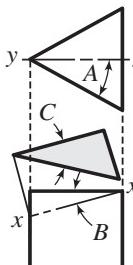


Fig. 1.

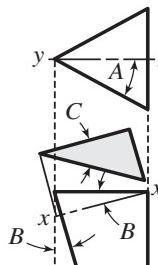


Fig. 2.

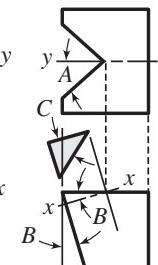


Fig. 3.

For given angles A and B , find the resultant angle C in plane $x-x$. Angle B is measured in vertical plane $y-y$ of midsection.

$$(Fig. 1) \quad \tan C = \tan A \times \cos B$$

$$(Fig. 2) \quad \tan C = \frac{\tan A}{\cos B}$$

(Fig. 3) (Same formula as for Fig. 2)

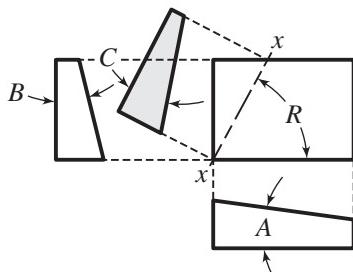


Fig. 4.

Fig. 4. In machining plate to angles A and B , it is held at angle C in plane $x-x$. Angle of rotation R in plane parallel to base (or complement of R) is for locating plate so that plane $x-x$ is perpendicular to axis of pivot on angle-plate or work-holding vise.

$$\tan R = \frac{\tan B}{\tan A}; \quad \tan C = \frac{\tan A}{\cos R}$$

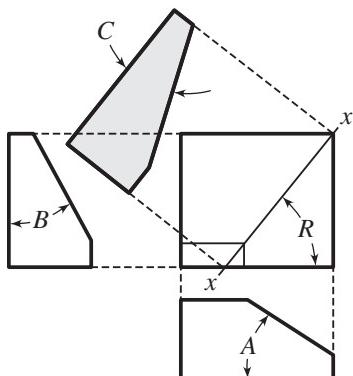


Fig. 5.

Fig. 5. Angle R in horizontal plane parallel to base is angle from plane $x-x$ to side having angle A .

$$\tan R = \frac{\tan A}{\tan B}$$

$\tan C = \tan A \cos R = \tan B \sin R$
Compound angle C is angle in plane $x-x$ from base to corner formed by intersection of planes inclined to angles A and B . This formula for C may be used to find cot of complement of C_1 , Fig. 6.

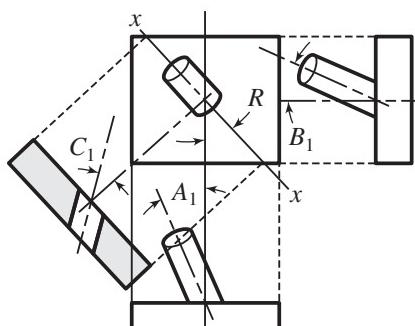


Fig. 6.

Fig. 6. Angles A_1 and B_1 are measured in vertical planes of front and side elevations. Plane $x-x$ is located by angle R from center-line or from plane of angle B_1 .

$$\tan R = \frac{\tan A_1}{\tan B_1}$$

$$\tan C_1 = \frac{\tan A_1}{\sin R} = \frac{\tan B_1}{\cos R}$$

The resultant angle C_1 would be required in drilling hole for pin.

C = compound angle in plane $x-x$ and is the resultant of angles A and B

Lengths of Chords for Spacing Off the Circumferences of Circles.—The table of the lengths of chords for spacing off the circumferences of circles is intended to make possible the division of the periphery into a number of equal parts without trials with the dividers. The table is calculated for circles having a diameter equal to 1. For circles of other diameters, the length of chord given in the table should be multiplied by the diameter of the circle. This table may be used by toolmakers when setting “buttons” in circular formation.

Example: Assume that it is required to divide the periphery of a circle of 20 inches diameter into thirty-two equal parts.

From the table the length of the chord is found to be 0.098017 inch, if the diameter of the circle were 1 inch. With a diameter of 20 inches the length of the chord for one division would be $20 \times 0.098017 = 1.9603$ inches.

Example, Metric Units: For a 100 millimeter diameter requiring 5 equal divisions, the length of the chord for one division would be $100 \times 0.587785 = 58.7785$ millimeters.

Lengths of Chords for Spacing Off the Circumferences of Circles with a Diameter Equal to 1 (English or metric units)

| No. of Spaces | Length of Chord |
|---------------|-----------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
| 3 | 0.866025 | 22 | 0.142315 | 41 | 0.076549 | 60 | 0.052336 |
| 4 | 0.707107 | 23 | 0.136167 | 42 | 0.074730 | 61 | 0.051479 |
| 5 | 0.587785 | 24 | 0.130526 | 43 | 0.072995 | 62 | 0.050649 |
| 6 | 0.500000 | 25 | 0.125333 | 44 | 0.071339 | 63 | 0.049846 |
| 7 | 0.433884 | 26 | 0.120537 | 45 | 0.069756 | 64 | 0.049068 |
| 8 | 0.382683 | 27 | 0.116093 | 46 | 0.068242 | 65 | 0.048313 |
| 9 | 0.342020 | 28 | 0.111964 | 47 | 0.066793 | 66 | 0.047582 |
| 10 | 0.309017 | 29 | 0.108119 | 48 | 0.065403 | 67 | 0.046872 |
| 11 | 0.281733 | 30 | 0.104528 | 49 | 0.064070 | 68 | 0.046183 |
| 12 | 0.258819 | 31 | 0.101168 | 50 | 0.062791 | 69 | 0.045515 |
| 13 | 0.239316 | 32 | 0.098017 | 51 | 0.061561 | 70 | 0.044865 |
| 14 | 0.222521 | 33 | 0.095056 | 52 | 0.060378 | 71 | 0.044233 |
| 15 | 0.207912 | 34 | 0.092268 | 53 | 0.059241 | 72 | 0.043619 |
| 16 | 0.195090 | 35 | 0.089639 | 54 | 0.058145 | 73 | 0.043022 |
| 17 | 0.183750 | 36 | 0.087156 | 55 | 0.057089 | 74 | 0.042441 |
| 18 | 0.173648 | 37 | 0.084806 | 56 | 0.056070 | 75 | 0.041876 |
| 19 | 0.164595 | 38 | 0.082579 | 57 | 0.055088 | 76 | 0.041325 |
| 20 | 0.156434 | 39 | 0.080467 | 58 | 0.054139 | 77 | 0.040789 |
| 21 | 0.149042 | 40 | 0.078459 | 59 | 0.053222 | 78 | 0.040266 |

For circles of other diameters, multiply length given in table by diameter of circle.

Coordinates for Locating Equally-spaced Holes (English or metric units)

| Multiply values shown by diameter of pitch circle. | |
|--|---|
| | 3-Hole $A = 0.25000$ $B = 0.43301$ $C = 0.86603$ |
| | 8-Hole $A = 0.27059$ $B = 0.27059$ $C = 0.46194$ $D = 0.19134$ |
| | 5-Hole $A = 0.18164$ $B = 0.55902$ $C = 0.40451$ $D = 0.29389$ |
| | 9-Hole $A = 0.46985$ $B = 0.17101$ $C = 0.26201$ $D = 0.21985$ $E = 0.38302$ $F = 0.32139$ $G = 0.17101$ $H = 0.29620$ |
| | 6-Hole $A = 0.43301$ $B = 0.25000$ $C = 0.50000$ |
| | 10-Hole $A = 0.29389$ $B = 0.09549$ $C = 0.18164$ $D = 0.25000$ $E = 0.15451$ |
| | 7-Hole $A = 0.27052$ $B = 0.33922$ $C = 0.45049$ $D = 0.21694$ $E = 0.31175$ $F = 0.39092$ |
| | 11-Hole $A = 0.47975$ $B = 0.14087$ $C = 0.23700$ $D = 0.15231$ $E = 0.11704$ $F = 0.25627$ $G = 0.42063$ $H = 0.27032$ $K = 0.18449$ $L = 0.21291$ |
| | 8-Hole $A = 0.35355$ $B = 0.14645$ |
| | 12-Hole $A = 0.22415$ $B = 0.12941$ $C = 0.48296$ $D = 0.12941$ $E = 0.25882$ |

The constants in the table are multiplied by the diameter of the bolt-hole pitch circle to obtain the longitudinal and lateral adjustments of the right angle-slides of the jig borer in boring equally spaced holes. While holes may be located by these right-angular measurements, an auxiliary rotary table provides a more direct method. With a rotary table, the holes are spaced by precise angular movements after adjustment to the required radius.

**Decimal Equivalents, Squares, Cubes, Square Roots, Cube Roots,
and Logarithms of Fractions from $\frac{1}{64}$ to 1, by 64ths**

| Frac-tion | Deci-mal Equiva-lent | Log | Square | Log of Square | Cube | Log of Cube | Square Root | Log of Square Root | Cube Root | Log of Cube Root |
|-----------------|----------------------|----------|---------|---------------|---------|-------------|-------------|--------------------|-----------|------------------|
| $\frac{1}{64}$ | 0.015625 | -1.80618 | 0.00024 | -3.61236 | 0.00000 | -5.41854 | 0.12500 | -0.90309 | 0.25000 | -0.60206 |
| $\frac{1}{32}$ | 0.031250 | -1.50515 | 0.00098 | -3.01030 | 0.00003 | -4.51545 | 0.17678 | -0.75257 | 0.31498 | -0.50172 |
| $\frac{3}{64}$ | 0.046875 | -1.32906 | 0.00220 | -2.65812 | 0.00010 | -3.98718 | 0.21651 | -0.66453 | 0.36056 | -0.44302 |
| $\frac{1}{16}$ | 0.062500 | -1.20412 | 0.00391 | -2.40824 | 0.00024 | -3.61236 | 0.25000 | -0.60206 | 0.39685 | -0.40137 |
| $\frac{5}{64}$ | 0.078125 | -1.10721 | 0.00610 | -2.21442 | 0.00048 | -3.32163 | 0.27951 | -0.55361 | 0.42749 | -0.36907 |
| $\frac{3}{32}$ | 0.093750 | -1.02803 | 0.00879 | -2.05606 | 0.00082 | -3.08409 | 0.30619 | -0.51402 | 0.45428 | -0.34268 |
| $\frac{7}{64}$ | 0.109375 | -0.96108 | 0.01196 | -1.92216 | 0.00131 | -2.88325 | 0.33072 | -0.48054 | 0.47823 | -0.32036 |
| $\frac{1}{8}$ | 0.125000 | -0.90309 | 0.01563 | -1.80618 | 0.00195 | -2.70927 | 0.35355 | -0.45155 | 0.50000 | -0.30103 |
| $\frac{9}{64}$ | 0.140625 | -0.85194 | 0.01978 | -1.70388 | 0.00278 | -2.55581 | 0.37500 | -0.42597 | 0.52002 | -0.28398 |
| $\frac{5}{32}$ | 0.156250 | -0.80618 | 0.02441 | -1.61236 | 0.00381 | -2.41854 | 0.39529 | -0.40309 | 0.53861 | -0.26873 |
| $\frac{11}{64}$ | 0.171875 | -0.76479 | 0.02954 | -1.52958 | 0.00508 | -2.29436 | 0.41458 | -0.38239 | 0.55600 | -0.25493 |
| $\frac{3}{16}$ | 0.187500 | -0.72700 | 0.03516 | -1.45400 | 0.00659 | -2.18100 | 0.43301 | -0.36350 | 0.57236 | -0.24233 |
| $\frac{13}{64}$ | 0.203125 | -0.69224 | 0.04126 | -1.38447 | 0.00838 | -2.07671 | 0.45069 | -0.34612 | 0.58783 | -0.23075 |
| $\frac{7}{32}$ | 0.218750 | -0.66005 | 0.04785 | -1.32010 | 0.01047 | -1.98016 | 0.46771 | -0.33003 | 0.60254 | -0.22002 |
| $\frac{15}{64}$ | 0.234375 | -0.63009 | 0.05493 | -1.26018 | 0.01287 | -1.89027 | 0.48412 | -0.31504 | 0.61655 | -0.21003 |
| $\frac{1}{4}$ | 0.250000 | -0.60206 | 0.06250 | -1.20412 | 0.01563 | -1.80618 | 0.50000 | -0.30103 | 0.62996 | -0.20069 |
| $\frac{17}{64}$ | 0.265625 | -0.57573 | 0.07056 | -1.15146 | 0.01874 | -1.72719 | 0.51539 | -0.28787 | 0.64282 | -0.19191 |
| $\frac{9}{32}$ | 0.281250 | -0.55091 | 0.07910 | -1.10182 | 0.02225 | -1.65272 | 0.53033 | -0.27545 | 0.65519 | -0.18364 |
| $\frac{19}{64}$ | 0.296875 | -0.52743 | 0.08813 | -1.05485 | 0.02617 | -1.58228 | 0.54486 | -0.26371 | 0.66710 | -0.17581 |
| $\frac{5}{16}$ | 0.312500 | -0.50515 | 0.09766 | -1.01030 | 0.03052 | -1.51545 | 0.55902 | -0.25258 | 0.67860 | -0.16838 |
| $\frac{21}{64}$ | 0.328125 | -0.48396 | 0.10767 | -0.96792 | 0.03533 | -1.45188 | 0.57282 | -0.24198 | 0.68973 | -0.16132 |
| $\frac{11}{32}$ | 0.343750 | -0.46376 | 0.11816 | -0.92752 | 0.04062 | -1.39127 | 0.58630 | -0.23188 | 0.70051 | -0.15459 |
| $\frac{23}{64}$ | 0.359375 | -0.44445 | 0.12915 | -0.88890 | 0.04641 | -1.33336 | 0.59948 | -0.22223 | 0.71097 | -0.14815 |
| $\frac{3}{8}$ | 0.375000 | -0.42597 | 0.14063 | -0.85194 | 0.05273 | -1.27791 | 0.61237 | -0.21299 | 0.72113 | -0.14199 |
| $\frac{25}{64}$ | 0.390625 | -0.40824 | 0.15259 | -0.81648 | 0.05960 | -1.22472 | 0.62500 | -0.20412 | 0.73100 | -0.13608 |
| $\frac{13}{32}$ | 0.406250 | -0.39121 | 0.16504 | -0.78241 | 0.06705 | -1.17362 | 0.63738 | -0.19560 | 0.74062 | -0.13040 |
| $\frac{27}{64}$ | 0.421875 | -0.37482 | 0.17798 | -0.74963 | 0.07508 | -1.12445 | 0.64952 | -0.18741 | 0.75000 | -0.12494 |
| $\frac{7}{16}$ | 0.437500 | -0.35902 | 0.19141 | -0.71804 | 0.08374 | -1.07707 | 0.66144 | -0.17951 | 0.75915 | -0.11967 |
| $\frac{29}{64}$ | 0.453125 | -0.34378 | 0.20532 | -0.68756 | 0.09304 | -1.03135 | 0.67315 | -0.17189 | 0.76808 | -0.11459 |
| $\frac{15}{32}$ | 0.468750 | -0.32906 | 0.21973 | -0.65812 | 0.10300 | -0.98718 | 0.68465 | -0.16453 | 0.77681 | -0.10969 |
| $\frac{31}{64}$ | 0.484375 | -0.31482 | 0.23462 | -0.62964 | 0.11364 | -0.94446 | 0.69597 | -0.15741 | 0.78535 | -0.10494 |
| $\frac{1}{2}$ | 0.500000 | -0.30103 | 0.25000 | -0.60206 | 0.12500 | -0.90309 | 0.70711 | -0.15052 | 0.79370 | -0.10034 |

**Decimal Equivalents, Squares, Cubes, Square Roots, Cube Roots,
and Logarithms of Fractions from $\frac{1}{64}$ to 1, by 64ths (Continued)**

| Frac-tion | Deci-mal Equiva-lent | Log | Square | Log of Square | Cube | Log of Cube | Square Root | Log of Square Root | Cube Root | Log of Cube Root |
|-----------------|----------------------|----------|---------|---------------|---------|-------------|-------------|--------------------|-----------|------------------|
| $\frac{33}{64}$ | 0.515625 | -0.28767 | 0.26587 | -0.57533 | 0.13709 | -0.86300 | 0.71807 | -0.14383 | 0.80188 | -0.09589 |
| $\frac{17}{32}$ | 0.531250 | -0.27470 | 0.28223 | -0.54940 | 0.14993 | -0.82410 | 0.72887 | -0.13735 | 0.80990 | -0.09157 |
| $\frac{35}{64}$ | 0.546875 | -0.26211 | 0.29907 | -0.52422 | 0.16356 | -0.78634 | 0.73951 | -0.13106 | 0.81777 | -0.08737 |
| $\frac{9}{16}$ | 0.562500 | -0.24988 | 0.31641 | -0.49976 | 0.17798 | -0.74963 | 0.75000 | -0.12494 | 0.82548 | -0.08329 |
| $\frac{37}{64}$ | 0.578125 | -0.23798 | 0.33423 | -0.47596 | 0.19323 | -0.71394 | 0.76035 | -0.11899 | 0.83306 | -0.07933 |
| $\frac{19}{32}$ | 0.593750 | -0.22640 | 0.35254 | -0.45279 | 0.20932 | -0.67919 | 0.77055 | -0.11320 | 0.84049 | -0.07547 |
| $\frac{39}{64}$ | 0.609375 | -0.21512 | 0.37134 | -0.43023 | 0.22628 | -0.64535 | 0.78063 | -0.10756 | 0.84780 | -0.07171 |
| $\frac{5}{8}$ | 0.625000 | -0.20412 | 0.39063 | -0.40824 | 0.24414 | -0.61236 | 0.79057 | -0.10206 | 0.85499 | -0.06804 |
| $\frac{41}{64}$ | 0.640625 | -0.19340 | 0.41040 | -0.38679 | 0.26291 | -0.58019 | 0.80039 | -0.09670 | 0.86205 | -0.06447 |
| $\frac{21}{32}$ | 0.656250 | -0.18293 | 0.43066 | -0.36586 | 0.28262 | -0.54879 | 0.81009 | -0.09147 | 0.86901 | -0.06098 |
| $\frac{43}{64}$ | 0.671875 | -0.17271 | 0.45142 | -0.34542 | 0.30330 | -0.51814 | 0.81968 | -0.08636 | 0.87585 | -0.05757 |
| $\frac{11}{16}$ | 0.687500 | -0.16273 | 0.47266 | -0.32546 | 0.32495 | -0.48818 | 0.82916 | -0.08136 | 0.88259 | -0.05424 |
| $\frac{45}{64}$ | 0.703125 | -0.15297 | 0.49438 | -0.30594 | 0.34761 | -0.45890 | 0.83853 | -0.07648 | 0.88922 | -0.05099 |
| $\frac{23}{32}$ | 0.718750 | -0.14342 | 0.51660 | -0.28684 | 0.37131 | -0.43027 | 0.84779 | -0.07171 | 0.89576 | -0.04781 |
| $\frac{47}{64}$ | 0.734375 | -0.13408 | 0.53931 | -0.26816 | 0.39605 | -0.40225 | 0.85696 | -0.06704 | 0.90221 | -0.04469 |
| $\frac{3}{4}$ | 0.750000 | -0.12494 | 0.56250 | -0.24988 | 0.42188 | -0.37482 | 0.86603 | -0.06247 | 0.90856 | -0.04165 |
| $\frac{49}{64}$ | 0.765625 | -0.11598 | 0.58618 | -0.23197 | 0.44880 | -0.34795 | 0.87500 | -0.05799 | 0.91483 | -0.03866 |
| $\frac{25}{32}$ | 0.781250 | -0.10721 | 0.61035 | -0.21442 | 0.47684 | -0.32163 | 0.88388 | -0.05361 | 0.92101 | -0.03574 |
| $\frac{51}{64}$ | 0.796875 | -0.09861 | 0.63501 | -0.19722 | 0.50602 | -0.29583 | 0.89268 | -0.04931 | 0.92711 | -0.03287 |
| $\frac{13}{16}$ | 0.812500 | -0.09018 | 0.66016 | -0.18035 | 0.53638 | -0.27053 | 0.90139 | -0.04509 | 0.93313 | -0.03006 |
| $\frac{53}{64}$ | 0.828125 | -0.08190 | 0.68579 | -0.16381 | 0.56792 | -0.24571 | 0.91001 | -0.04095 | 0.93907 | -0.02730 |
| $\frac{27}{32}$ | 0.843750 | -0.07379 | 0.71191 | -0.14757 | 0.60068 | -0.22136 | 0.91856 | -0.03689 | 0.94494 | -0.02460 |
| $\frac{55}{64}$ | 0.859375 | -0.06582 | 0.73853 | -0.13164 | 0.63467 | -0.19745 | 0.92703 | -0.03291 | 0.95074 | -0.02194 |
| $\frac{7}{8}$ | 0.875000 | -0.05799 | 0.76563 | -0.11598 | 0.66992 | -0.17398 | 0.93541 | -0.02900 | 0.95647 | -0.01933 |
| $\frac{57}{64}$ | 0.890625 | -0.05031 | 0.79321 | -0.10061 | 0.70646 | -0.15092 | 0.94373 | -0.02515 | 0.96213 | -0.01677 |
| $\frac{29}{32}$ | 0.906250 | -0.04275 | 0.82129 | -0.08550 | 0.74429 | -0.12826 | 0.95197 | -0.02138 | 0.96772 | -0.01425 |
| $\frac{59}{64}$ | 0.921875 | -0.03533 | 0.84985 | -0.07066 | 0.78346 | -0.10598 | 0.96014 | -0.01766 | 0.97325 | -0.01178 |
| $\frac{15}{16}$ | 0.937500 | -0.02803 | 0.87891 | -0.05606 | 0.82397 | -0.08409 | 0.96825 | -0.01401 | 0.97872 | -0.00934 |
| $\frac{61}{64}$ | 0.953125 | -0.02085 | 0.90845 | -0.04170 | 0.86586 | -0.06255 | 0.97628 | -0.01043 | 0.98412 | -0.00695 |
| $\frac{31}{32}$ | 0.968750 | -0.01379 | 0.93848 | -0.02758 | 0.90915 | -0.04137 | 0.98425 | -0.00689 | 0.98947 | -0.00460 |
| $\frac{63}{64}$ | 0.984375 | -0.00684 | 0.96899 | -0.01368 | 0.95385 | -0.02052 | 0.99216 | -0.00342 | 0.99476 | -0.00228 |
| 1 | 1.000000 | 0.000000 | 1.00000 | 0.000000 | 1.00000 | 0.00000 | 1.00000 | 0.00000 | 1.00000 | 0.00000 |

Diameter, Circumference and Area of a Circle

| Diameter | Circumference | Area | Diameter | Circumference | Area | Diameter | Circumference | Area |
|------------------|---------------|--------|------------------|---------------|---------|------------------|---------------|--------|
| $\frac{1}{64}$ | 0.0491 | 0.0002 | 2 | 6.2832 | 3.1416 | 5 | 15.7080 | 19.635 |
| $\frac{1}{32}$ | 0.0982 | 0.0008 | $2\frac{1}{16}$ | 6.4795 | 3.3410 | $5\frac{1}{16}$ | 15.9043 | 20.129 |
| $\frac{1}{16}$ | 0.1963 | 0.0031 | $2\frac{1}{8}$ | 6.6759 | 3.5466 | $5\frac{1}{8}$ | 16.1007 | 20.629 |
| $\frac{3}{32}$ | 0.2945 | 0.0069 | $2\frac{3}{16}$ | 6.8722 | 3.7583 | $5\frac{3}{16}$ | 16.2970 | 21.135 |
| $\frac{1}{8}$ | 0.3927 | 0.0123 | $2\frac{1}{4}$ | 7.0686 | 3.9761 | $5\frac{1}{4}$ | 16.4934 | 21.648 |
| $\frac{5}{32}$ | 0.4909 | 0.0192 | $2\frac{5}{16}$ | 7.2649 | 4.2000 | $5\frac{5}{16}$ | 16.6897 | 22.166 |
| $\frac{3}{16}$ | 0.5890 | 0.0276 | $2\frac{3}{8}$ | 7.4613 | 4.4301 | $5\frac{3}{8}$ | 16.8861 | 22.691 |
| $\frac{7}{32}$ | 0.6872 | 0.0376 | $2\frac{7}{16}$ | 7.6576 | 4.6664 | $5\frac{7}{16}$ | 17.0824 | 23.221 |
| $\frac{1}{4}$ | 0.7854 | 0.0491 | $2\frac{1}{2}$ | 7.8540 | 4.9087 | $5\frac{1}{2}$ | 17.2788 | 23.758 |
| $\frac{9}{32}$ | 0.8836 | 0.0621 | $2\frac{9}{16}$ | 8.0503 | 5.1572 | $5\frac{9}{16}$ | 17.4751 | 24.301 |
| $\frac{5}{16}$ | 0.9817 | 0.0767 | $2\frac{5}{8}$ | 8.2467 | 5.4119 | $5\frac{5}{8}$ | 17.6715 | 24.850 |
| $1\frac{1}{32}$ | 1.0799 | 0.0928 | $2\frac{11}{16}$ | 8.4430 | 5.6727 | $5\frac{11}{16}$ | 17.8678 | 25.406 |
| $\frac{3}{8}$ | 1.1781 | 0.1104 | $2\frac{3}{4}$ | 8.6394 | 5.9396 | $5\frac{3}{4}$ | 18.0642 | 25.967 |
| $1\frac{3}{32}$ | 1.2763 | 0.1296 | $2\frac{13}{16}$ | 8.8357 | 6.2126 | $5\frac{13}{16}$ | 18.2605 | 26.535 |
| $\frac{7}{16}$ | 1.3744 | 0.1503 | $2\frac{7}{8}$ | 9.0321 | 6.4918 | $5\frac{7}{8}$ | 18.4569 | 27.109 |
| $1\frac{5}{32}$ | 1.4726 | 0.1726 | $2\frac{15}{16}$ | 9.2284 | 6.7771 | $5\frac{15}{16}$ | 18.6532 | 27.688 |
| $\frac{1}{2}$ | 1.5708 | 0.1963 | 3 | 9.4248 | 7.0686 | 6 | 18.8496 | 28.274 |
| $1\frac{7}{32}$ | 1.6690 | 0.2217 | $3\frac{1}{16}$ | 9.6211 | 7.3662 | $6\frac{1}{8}$ | 19.2423 | 29.465 |
| $\frac{9}{16}$ | 1.7671 | 0.2485 | $3\frac{1}{8}$ | 9.8175 | 7.6699 | $6\frac{1}{4}$ | 19.6350 | 30.680 |
| $1\frac{9}{32}$ | 1.8653 | 0.2769 | $3\frac{3}{16}$ | 10.0138 | 7.9798 | $6\frac{3}{8}$ | 20.0277 | 31.919 |
| $\frac{5}{8}$ | 1.9635 | 0.3068 | $3\frac{1}{4}$ | 10.2102 | 8.2958 | $6\frac{1}{2}$ | 20.4204 | 33.183 |
| $2\frac{1}{32}$ | 2.0617 | 0.3382 | $3\frac{5}{16}$ | 10.4065 | 8.6179 | $6\frac{5}{8}$ | 20.8131 | 34.472 |
| $1\frac{11}{16}$ | 2.1598 | 0.3712 | $3\frac{3}{8}$ | 10.6029 | 8.9462 | $6\frac{3}{4}$ | 21.2058 | 35.785 |
| $2\frac{3}{32}$ | 2.2580 | 0.4057 | $3\frac{7}{16}$ | 10.7992 | 9.2806 | $6\frac{7}{8}$ | 21.5984 | 37.122 |
| $\frac{3}{4}$ | 2.3562 | 0.4418 | $3\frac{1}{2}$ | 10.9956 | 9.6211 | 7 | 21.9911 | 38.485 |
| $2\frac{5}{32}$ | 2.4544 | 0.4794 | $3\frac{9}{16}$ | 11.1919 | 9.9678 | $7\frac{1}{8}$ | 22.3838 | 39.871 |
| $1\frac{13}{16}$ | 2.5525 | 0.5185 | $3\frac{5}{8}$ | 11.388 | 10.3206 | $7\frac{1}{4}$ | 22.7765 | 41.282 |
| $2\frac{7}{32}$ | 2.6507 | 0.5591 | $3\frac{11}{16}$ | 11.585 | 10.6796 | $7\frac{3}{8}$ | 23.1692 | 42.718 |
| $\frac{7}{8}$ | 2.7489 | 0.6013 | $3\frac{3}{4}$ | 11.781 | 11.0447 | $7\frac{1}{2}$ | 23.5619 | 44.179 |
| $2\frac{9}{32}$ | 2.8471 | 0.6450 | $3\frac{13}{16}$ | 11.977 | 11.4159 | $7\frac{5}{8}$ | 23.9546 | 45.664 |
| $1\frac{15}{16}$ | 2.9452 | 0.6903 | $3\frac{7}{8}$ | 12.174 | 11.7932 | $7\frac{3}{4}$ | 24.3473 | 47.173 |
| $3\frac{1}{32}$ | 3.0434 | 0.7371 | $3\frac{15}{16}$ | 12.370 | 12.1767 | $7\frac{7}{8}$ | 24.7400 | 48.707 |
| 1 | 3.1416 | 0.7854 | 4 | 12.566 | 12.5664 | 8 | 25.1327 | 50.265 |
| $1\frac{1}{16}$ | 3.3379 | 0.8866 | $4\frac{1}{16}$ | 12.763 | 12.9621 | $8\frac{1}{8}$ | 25.5254 | 51.849 |
| $1\frac{1}{8}$ | 3.5343 | 0.9940 | $4\frac{1}{8}$ | 12.959 | 13.3640 | $8\frac{1}{4}$ | 25.9181 | 53.456 |
| $1\frac{3}{16}$ | 3.7306 | 1.1075 | $4\frac{3}{16}$ | 13.155 | 13.7721 | $8\frac{3}{8}$ | 26.3108 | 55.088 |
| $1\frac{1}{4}$ | 3.9270 | 1.2272 | $4\frac{1}{4}$ | 13.352 | 14.1863 | $8\frac{1}{2}$ | 26.7035 | 56.745 |
| $1\frac{5}{16}$ | 4.1233 | 1.3530 | $4\frac{5}{16}$ | 13.548 | 14.6066 | $8\frac{5}{8}$ | 27.0962 | 58.426 |
| $1\frac{3}{8}$ | 4.3197 | 1.4849 | $4\frac{3}{8}$ | 13.744 | 15.0330 | $8\frac{3}{4}$ | 27.4889 | 60.132 |
| $1\frac{1}{16}$ | 4.5160 | 1.6230 | $4\frac{7}{16}$ | 13.941 | 15.4656 | $8\frac{7}{8}$ | 27.8816 | 61.862 |
| $1\frac{1}{2}$ | 4.7124 | 1.7671 | $4\frac{1}{2}$ | 14.137 | 15.9043 | 9 | 28.2743 | 63.617 |
| $1\frac{1}{16}$ | 4.9087 | 1.9175 | $4\frac{9}{16}$ | 14.334 | 16.3492 | $9\frac{1}{8}$ | 28.6670 | 65.397 |
| $1\frac{1}{8}$ | 5.1051 | 2.0739 | $4\frac{5}{8}$ | 14.530 | 16.8002 | $9\frac{1}{4}$ | 29.0597 | 67.201 |
| $1\frac{11}{16}$ | 5.3014 | 2.2365 | $4\frac{11}{16}$ | 14.726 | 17.2573 | $9\frac{3}{8}$ | 29.4524 | 69.029 |
| $1\frac{3}{4}$ | 5.4978 | 2.4053 | $4\frac{3}{4}$ | 14.923 | 17.7205 | $9\frac{1}{2}$ | 29.8451 | 70.882 |
| $1\frac{13}{16}$ | 5.6941 | 2.5802 | $4\frac{13}{16}$ | 15.119 | 18.1899 | $9\frac{5}{8}$ | 30.2378 | 72.760 |
| $1\frac{7}{8}$ | 5.8905 | 2.7612 | $4\frac{7}{8}$ | 15.315 | 18.6655 | $9\frac{3}{4}$ | 30.6305 | 74.662 |
| $1\frac{15}{16}$ | 6.0868 | 2.9483 | $4\frac{15}{16}$ | 15.512 | 19.1471 | $9\frac{7}{8}$ | 31.0232 | 76.589 |

MEASUREMENT AND INSPECTION

Sine Bar

The sine bar is used either for very accurate angular measurements or for locating work at a given angle as, for example, in surface grinding templates, gages, etc. The sine bar is especially useful in measuring or checking angles when the limit of accuracy is 5 minutes or less. Some bevel protractors are equipped with verniers which read to 5 minutes but the setting depends upon the alignment of graduations whereas a sine bar usually is located by positive contact with precision gage-blocks selected for whatever dimension is required for obtaining a given angle.

Types of Sine Bars.—A sine bar consists of a hardened, ground and lapped steel bar with very accurate cylindrical plugs of equal diameter attached to or near each end. The form illustrated by Fig. 1 has notched ends for receiving the cylindrical plugs so that they are held firmly against both faces of the notch. The standard center-to-center distance C between the plugs is either 5 or 10 inches. The upper and lower sides of sine bars are parallel to the center line of the plugs within very close limits.

The body of the sine bar ordinarily has several through holes to reduce the weight. In the making of the sine bar shown in, if too much material is removed from one locating notch, regrinding the shoulder at the opposite end would make it possible to obtain the correct center distance. That is the reason for this change in form. The type of sine bar illustrated by Fig. 3 has the cylindrical disks or plugs attached to one side. These differences in form or arrangement do not, of course, affect the principle governing the use of the sine bar. An accurate surface plate or master flat is always used in conjunction with a sine bar in order to form the base from which the vertical measurements are made.

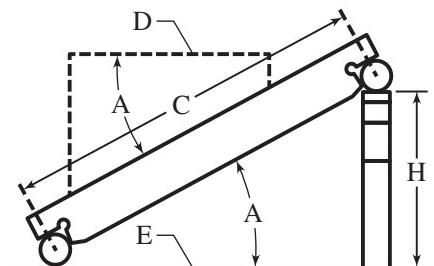


Fig. 1.

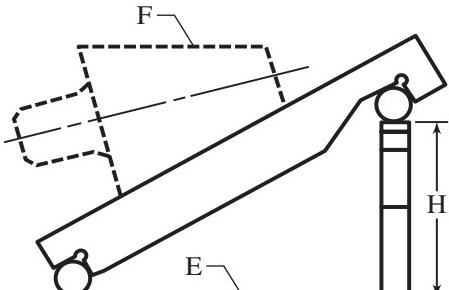


Fig. 2.

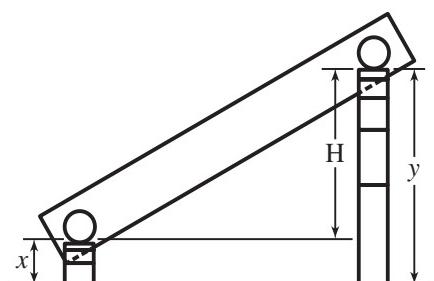


Fig. 3.

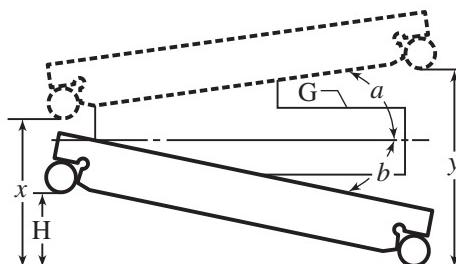


Fig. 4.

Setting a Sine Bar to a Given Angle.—To find the vertical distance H , for setting a sine bar to the required angle, convert the angle to decimal form on a pocket calculator, take the sine of that angle, and multiply by the distance between the cylinders. For example, if an angle of 31 degrees, 30 minutes is required, the equivalent angle is 31 degrees plus $\frac{30}{60} = 31 + 0.5$, or 31.5 degrees. The sine of 31.5 degrees is 0.5225 and multiplying this value by the sine bar length gives 2.613 in. for the height H , Fig. 1 and 3, of the gage blocks.

Finding Angle when Height H of Sine Bar is Known.—To find the angle equivalent to a given height H , reverse the above procedure. Thus, if the height H is 1.4061 in., dividing by 5 gives a sine of 0.28122, which corresponds to an angle of 16.333 degrees, or 16 degrees 20 minutes.

Checking Angle of Templet or Gage by Using Sine Bar.—Place templet or gage on sine bar as indicated by dotted lines, Fig. 1. Clamps may be used to hold work in place. Place upper end of sine bar on gage blocks having total height H corresponding to the required angle. If upper edge D of work is parallel with surface plate E , then angle A of work equals angle A to which sine bar is set. Parallelism between edge D and surface plate may be tested by checking the height at each end with a dial gage or some type of indicating comparator.

Measuring Angle of Templet or Gage with Sine Bar.—To measure such an angle, adjust height of gage blocks and sine bar until edge D , Fig. 1, is parallel with surface plate E ; then find angle corresponding to height H , of gage blocks. For example, if height H is 2.5939 inches when D and E are parallel, the calculator will show that the angle A of the work is 31 degrees, 15 minutes.

Checking Taper per Foot with Sine Bar.—As an example, assume that the plug gage in Fig. 2 is supposed to have a taper of $6\frac{1}{8}$ inches per foot and taper is to be checked by using a 5-inch sine bar. The table of *Tapers per Foot and Corresponding Angles* on page 36 shows that the included angle for a taper of $6\frac{1}{8}$ inches per foot is 28 degrees 38 minutes 1 second, or 28.6336 degrees from the calculator. For a 5-inch sine bar, the calculator gives a value of 2.396 in. for the height H of the gage blocks. Using this height, if the upper surface F of the plug gage is parallel to the surface plate the angle corresponds to a taper of $6\frac{1}{8}$ inches per foot.

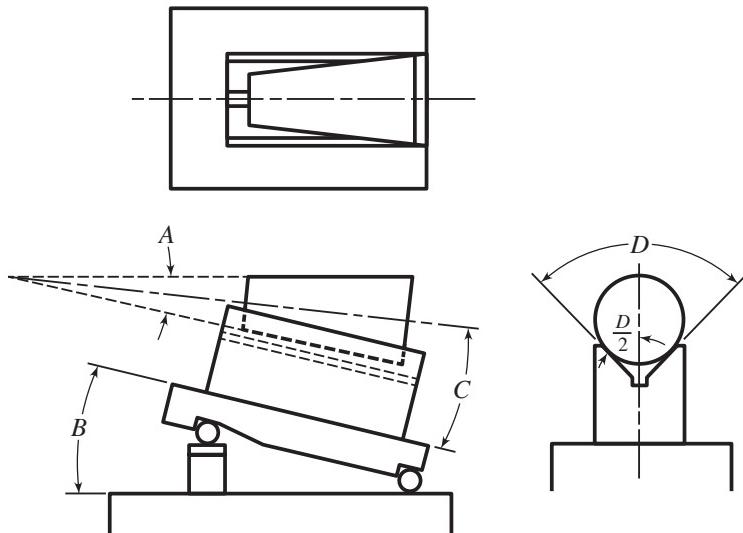
Setting Sine Bar having Plugs Attached to Side.—If the lower plug does not rest directly on the surface plate, as in Fig. 3, the height H for the sine bar is the difference between heights x and y , or the difference between the heights of the plugs; otherwise, the procedure in setting the sine bar and checking angles is the same as previously described.

Checking Templets Having Two Angles.—Assume that angle a of templet, Fig. 4, is 9 degrees, angle b 12 degrees, and that edge G is parallel to the surface plate. For an angle b of 12 degrees, the calculator shows that the height H is 1.03956 inches. For an angle a of 9 degrees, the difference between measurements x and y when the sine bar is in contact with the upper edge of the templet is 0.78217 inch.

Setting 10-inch Sine Bar to Given Angle.—A 10-inch sine bar may sometimes be preferred because of its longer working surface or because the longer center distance is conducive to greater precision. To obtain the vertical distances H for setting a 10-inch sine bar, multiply the sine of the angle by 10, by shifting the decimal point one place to the right.

For example, the sine of 39 degrees is 0.62932, hence the vertical height H for setting a 10-inch sine bar is 6.2932 inches.

Measuring Tapers with Vee-block and Sine Bar.— The taper on a conical part may be checked or found by placing the part in a vee-block which rests on the surface of a sine-plate or sine bar as shown in the accompanying diagram. The advantage of this method is that the axis of the vee-block may be aligned with the sides of the sine bar. Thus when the tapered part is placed in the vee-block it will be aligned perpendicular to the transverse axis of the sine bar.



The sine bar is set to angle $B = (C + A/2)$ where $A/2$ is one-half the included angle of the tapered part. If D is the included angle of the precision vee-block, the angle C is calculated from the formula:

$$\sin C = \frac{\sin(A/2)}{\sin(D/2)}$$

If dial indicator readings show no change across all points along the top of the taper surface, then this checks that the angle A of the taper is correct.

If the indicator readings vary, proceed as follows to find the actual angle of taper:
 1) Adjust the angle of the sine bar until the indicator reading is constant. Then find the new angle B' as explained in the paragraph *Measuring Angle of Templet or Gage with Sine Bar*; and 2) Using the angle B' calculate the actual half-angle $A'/2$ of the taper from the formula:.

$$\tan \frac{A'}{2} = \frac{\sin B'}{\csc \frac{D}{2} + \cos B'}$$

Constants for Setting a 5-inch Sine Bar for 1° to 7°

| Min. | 0° | 1° | 2° | 3° | 4° | 5° | 6° | 7° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 0.00000 | 0.08726 | 0.17450 | 0.26168 | 0.34878 | 0.43578 | 0.52264 | 0.60935 |
| 1 | 0.00145 | 0.08872 | 0.17595 | 0.26313 | 0.35023 | 0.43723 | 0.52409 | 0.61079 |
| 2 | 0.00291 | 0.09017 | 0.17740 | 0.26458 | 0.35168 | 0.43868 | 0.52554 | 0.61223 |
| 3 | 0.00436 | 0.09162 | 0.17886 | 0.26604 | 0.35313 | 0.44013 | 0.52698 | 0.61368 |
| 4 | 0.00582 | 0.09308 | 0.18031 | 0.26749 | 0.35459 | 0.44157 | 0.52843 | 0.61512 |
| 5 | 0.00727 | 0.09453 | 0.18177 | 0.26894 | 0.35604 | 0.44302 | 0.52987 | 0.61656 |
| 6 | 0.00873 | 0.09599 | 0.18322 | 0.27039 | 0.35749 | 0.44447 | 0.53132 | 0.61801 |
| 7 | 0.01018 | 0.09744 | 0.18467 | 0.27185 | 0.35894 | 0.44592 | 0.53277 | 0.61945 |
| 8 | 0.01164 | 0.09890 | 0.18613 | 0.27330 | 0.36039 | 0.44737 | 0.53421 | 0.62089 |
| 9 | 0.01309 | 0.10035 | 0.18758 | 0.27475 | 0.36184 | 0.44882 | 0.53566 | 0.62234 |
| 10 | 0.01454 | 0.10180 | 0.18903 | 0.27620 | 0.36329 | 0.45027 | 0.53710 | 0.62378 |
| 11 | 0.01600 | 0.10326 | 0.19049 | 0.27766 | 0.36474 | 0.45171 | 0.53855 | 0.62522 |
| 12 | 0.01745 | 0.10471 | 0.19194 | 0.27911 | 0.36619 | 0.45316 | 0.54000 | 0.62667 |
| 13 | 0.01891 | 0.10617 | 0.19339 | 0.28056 | 0.36764 | 0.45461 | 0.54144 | 0.62811 |
| 14 | 0.02036 | 0.10762 | 0.19485 | 0.28201 | 0.36909 | 0.45606 | 0.54289 | 0.62955 |
| 15 | 0.02182 | 0.10907 | 0.19630 | 0.28346 | 0.37054 | 0.45751 | 0.54433 | 0.63099 |
| 16 | 0.02327 | 0.11053 | 0.19775 | 0.28492 | 0.37199 | 0.45896 | 0.54578 | 0.63244 |
| 17 | 0.02473 | 0.11198 | 0.19921 | 0.28637 | 0.37344 | 0.46040 | 0.54723 | 0.63388 |
| 18 | 0.02618 | 0.11344 | 0.20066 | 0.28782 | 0.37489 | 0.46185 | 0.54867 | 0.63532 |
| 19 | 0.02763 | 0.11489 | 0.20211 | 0.28927 | 0.37634 | 0.46330 | 0.55012 | 0.63677 |
| 20 | 0.02909 | 0.11634 | 0.20357 | 0.29072 | 0.37779 | 0.46475 | 0.55156 | 0.63821 |
| 21 | 0.03054 | 0.11780 | 0.20502 | 0.29218 | 0.37924 | 0.46620 | 0.55301 | 0.63965 |
| 22 | 0.03200 | 0.11925 | 0.20647 | 0.29363 | 0.38069 | 0.46765 | 0.55445 | 0.64109 |
| 23 | 0.03345 | 0.12071 | 0.20793 | 0.29508 | 0.38214 | 0.46909 | 0.55590 | 0.64254 |
| 24 | 0.03491 | 0.12216 | 0.20938 | 0.29653 | 0.38360 | 0.47054 | 0.55734 | 0.64398 |
| 25 | 0.03636 | 0.12361 | 0.21083 | 0.29798 | 0.38505 | 0.47199 | 0.55879 | 0.64542 |
| 26 | 0.03782 | 0.12507 | 0.21228 | 0.29944 | 0.38650 | 0.47344 | 0.56024 | 0.64686 |
| 27 | 0.03927 | 0.12652 | 0.21374 | 0.30089 | 0.38795 | 0.47489 | 0.56168 | 0.64830 |
| 28 | 0.04072 | 0.12798 | 0.21519 | 0.30234 | 0.38940 | 0.47633 | 0.56313 | 0.64975 |
| 29 | 0.04218 | 0.12943 | 0.21664 | 0.30379 | 0.39085 | 0.47778 | 0.56457 | 0.65119 |
| 30 | 0.04363 | 0.13088 | 0.21810 | 0.30524 | 0.39230 | 0.47923 | 0.56602 | 0.65263 |
| 31 | 0.04509 | 0.13234 | 0.21955 | 0.30669 | 0.39375 | 0.48068 | 0.56746 | 0.65407 |
| 32 | 0.04654 | 0.13379 | 0.22100 | 0.30815 | 0.39520 | 0.48212 | 0.56891 | 0.65551 |
| 33 | 0.04800 | 0.13525 | 0.22246 | 0.30960 | 0.39665 | 0.48357 | 0.57035 | 0.65696 |
| 34 | 0.04945 | 0.13670 | 0.22391 | 0.31105 | 0.39810 | 0.48502 | 0.57180 | 0.65840 |
| 35 | 0.05090 | 0.13815 | 0.22536 | 0.31250 | 0.39954 | 0.48647 | 0.57324 | 0.65984 |
| 36 | 0.05236 | 0.13961 | 0.22681 | 0.31395 | 0.40099 | 0.48791 | 0.57469 | 0.66128 |
| 37 | 0.05381 | 0.14106 | 0.22827 | 0.31540 | 0.40244 | 0.48936 | 0.57613 | 0.66272 |
| 38 | 0.05527 | 0.14252 | 0.22972 | 0.31686 | 0.40389 | 0.49081 | 0.57758 | 0.66417 |
| 39 | 0.05672 | 0.14397 | 0.23117 | 0.31831 | 0.40534 | 0.49226 | 0.57902 | 0.66561 |
| 40 | 0.05818 | 0.14542 | 0.23263 | 0.31976 | 0.40679 | 0.49370 | 0.58046 | 0.66705 |
| 41 | 0.05963 | 0.14688 | 0.23408 | 0.32121 | 0.40824 | 0.49515 | 0.58191 | 0.66849 |
| 42 | 0.06109 | 0.14833 | 0.23553 | 0.32266 | 0.40969 | 0.49660 | 0.58335 | 0.66993 |
| 43 | 0.06254 | 0.14979 | 0.23699 | 0.32411 | 0.41114 | 0.49805 | 0.58480 | 0.67137 |
| 44 | 0.06399 | 0.15124 | 0.23844 | 0.32556 | 0.41259 | 0.49949 | 0.58624 | 0.67281 |
| 45 | 0.06545 | 0.15269 | 0.23989 | 0.32702 | 0.41404 | 0.50094 | 0.58769 | 0.67425 |
| 46 | 0.06690 | 0.15415 | 0.24134 | 0.32847 | 0.41549 | 0.50239 | 0.58913 | 0.67570 |
| 47 | 0.06836 | 0.15560 | 0.24280 | 0.32992 | 0.41694 | 0.50383 | 0.59058 | 0.67714 |
| 48 | 0.06981 | 0.15705 | 0.24425 | 0.33137 | 0.41839 | 0.50528 | 0.59202 | 0.67858 |
| 49 | 0.07127 | 0.15851 | 0.24570 | 0.33282 | 0.41984 | 0.50673 | 0.59346 | 0.68002 |
| 50 | 0.07272 | 0.15996 | 0.24715 | 0.33427 | 0.42129 | 0.50818 | 0.59491 | 0.68146 |
| 51 | 0.07417 | 0.16141 | 0.24861 | 0.33572 | 0.42274 | 0.50962 | 0.59635 | 0.68290 |
| 52 | 0.07563 | 0.16287 | 0.25006 | 0.33717 | 0.42419 | 0.51107 | 0.59780 | 0.68434 |
| 53 | 0.07708 | 0.16432 | 0.25151 | 0.33863 | 0.42564 | 0.51252 | 0.59924 | 0.68578 |
| 54 | 0.07854 | 0.16578 | 0.25296 | 0.34008 | 0.42708 | 0.51396 | 0.60068 | 0.68722 |
| 55 | 0.07999 | 0.16723 | 0.25442 | 0.34153 | 0.42853 | 0.51541 | 0.60213 | 0.68866 |
| 56 | 0.08145 | 0.16868 | 0.25587 | 0.34298 | 0.42998 | 0.51686 | 0.60357 | 0.69010 |
| 57 | 0.08290 | 0.17014 | 0.25732 | 0.34443 | 0.43143 | 0.51830 | 0.60502 | 0.69154 |
| 58 | 0.08435 | 0.17159 | 0.25877 | 0.34588 | 0.43288 | 0.51975 | 0.60646 | 0.69298 |
| 59 | 0.08581 | 0.17304 | 0.26023 | 0.34733 | 0.43433 | 0.52120 | 0.60790 | 0.69443 |
| 60 | 0.08726 | 0.17450 | 0.26168 | 0.34878 | 0.43578 | 0.52264 | 0.60935 | 0.69587 |

Constants for Setting a 5-inch Sine Bar for 8° to 15°

| Min. | 8° | 9° | 10° | 11° | 12° | 13° | 14° | 15° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 0.69587 | 0.78217 | 0.86824 | 0.95404 | 1.03956 | 1.12476 | 1.20961 | 1.29410 |
| 1 | 0.69731 | 0.78361 | 0.86967 | 0.95547 | 1.04098 | 1.12617 | 1.21102 | 1.29550 |
| 2 | 0.69875 | 0.78505 | 0.87111 | 0.95690 | 1.04240 | 1.12759 | 1.21243 | 1.29690 |
| 3 | 0.70019 | 0.78648 | 0.87254 | 0.95833 | 1.04383 | 1.12901 | 1.21384 | 1.29831 |
| 4 | 0.70163 | 0.78792 | 0.87397 | 0.95976 | 1.04525 | 1.13042 | 1.21525 | 1.29971 |
| 5 | 0.70307 | 0.78935 | 0.87540 | 0.96118 | 1.04667 | 1.13184 | 1.21666 | 1.30112 |
| 6 | 0.70451 | 0.79079 | 0.87683 | 0.96261 | 1.04809 | 1.13326 | 1.21808 | 1.30252 |
| 7 | 0.70595 | 0.79223 | 0.87827 | 0.96404 | 1.04951 | 1.13467 | 1.21949 | 1.30393 |
| 8 | 0.70739 | 0.79366 | 0.87970 | 0.96546 | 1.05094 | 1.13609 | 1.22090 | 1.30533 |
| 9 | 0.70883 | 0.79510 | 0.88113 | 0.96689 | 1.05236 | 1.13751 | 1.22231 | 1.30673 |
| 10 | 0.71027 | 0.79653 | 0.88256 | 0.96832 | 1.05378 | 1.13892 | 1.22372 | 1.30814 |
| 11 | 0.71171 | 0.79797 | 0.88399 | 0.96974 | 1.05520 | 1.14034 | 1.22513 | 1.30954 |
| 12 | 0.71314 | 0.79941 | 0.88542 | 0.97117 | 1.05662 | 1.14175 | 1.22654 | 1.31095 |
| 13 | 0.71458 | 0.80084 | 0.88686 | 0.97260 | 1.05805 | 1.14317 | 1.22795 | 1.31235 |
| 14 | 0.71602 | 0.80228 | 0.88829 | 0.97403 | 1.05947 | 1.14459 | 1.22936 | 1.31375 |
| 15 | 0.71746 | 0.80371 | 0.88972 | 0.97545 | 1.06089 | 1.14600 | 1.23077 | 1.31516 |
| 16 | 0.71890 | 0.80515 | 0.89115 | 0.97688 | 1.06231 | 1.14742 | 1.23218 | 1.31656 |
| 17 | 0.72034 | 0.80658 | 0.89258 | 0.97830 | 1.06373 | 1.14883 | 1.23359 | 1.31796 |
| 18 | 0.72178 | 0.80802 | 0.89401 | 0.97973 | 1.06515 | 1.15025 | 1.23500 | 1.31937 |
| 19 | 0.72322 | 0.80945 | 0.89544 | 0.98116 | 1.06657 | 1.15166 | 1.23640 | 1.32077 |
| 20 | 0.72466 | 0.81089 | 0.89687 | 0.98258 | 1.06799 | 1.15308 | 1.23781 | 1.32217 |
| 21 | 0.72610 | 0.81232 | 0.89830 | 0.98401 | 1.06941 | 1.15449 | 1.23922 | 1.32357 |
| 22 | 0.72754 | 0.81376 | 0.89973 | 0.98544 | 1.07084 | 1.15591 | 1.24063 | 1.32498 |
| 23 | 0.72898 | 0.81519 | 0.90117 | 0.98686 | 1.07226 | 1.15732 | 1.24204 | 1.32638 |
| 24 | 0.73042 | 0.81663 | 0.90260 | 0.98829 | 1.07368 | 1.15874 | 1.24345 | 1.32778 |
| 25 | 0.73185 | 0.81806 | 0.90403 | 0.98971 | 1.07510 | 1.16015 | 1.24486 | 1.32918 |
| 26 | 0.73329 | 0.81950 | 0.90546 | 0.99114 | 1.07652 | 1.16157 | 1.24627 | 1.33058 |
| 27 | 0.73473 | 0.82093 | 0.90689 | 0.99256 | 1.07794 | 1.16298 | 1.24768 | 1.33199 |
| 28 | 0.73617 | 0.82237 | 0.90832 | 0.99399 | 1.07936 | 1.16440 | 1.24908 | 1.33339 |
| 29 | 0.73761 | 0.82380 | 0.90975 | 0.99541 | 1.08078 | 1.16581 | 1.25049 | 1.33479 |
| 30 | 0.73905 | 0.82524 | 0.91118 | 0.99684 | 1.08220 | 1.16723 | 1.25190 | 1.33619 |
| 31 | 0.74049 | 0.82667 | 0.91261 | 0.99826 | 1.08362 | 1.16864 | 1.25331 | 1.33759 |
| 32 | 0.74192 | 0.82811 | 0.91404 | 0.99969 | 1.08504 | 1.17006 | 1.25472 | 1.33899 |
| 33 | 0.74336 | 0.82954 | 0.91547 | 1.00112 | 1.08646 | 1.17147 | 1.25612 | 1.34040 |
| 34 | 0.74480 | 0.83098 | 0.91690 | 1.00254 | 1.08788 | 1.17288 | 1.25753 | 1.34180 |
| 35 | 0.74624 | 0.83241 | 0.91833 | 1.00396 | 1.08930 | 1.17430 | 1.25894 | 1.34320 |
| 36 | 0.74768 | 0.83384 | 0.91976 | 1.00539 | 1.09072 | 1.17571 | 1.26035 | 1.34460 |
| 37 | 0.74911 | 0.83528 | 0.92119 | 1.00681 | 1.09214 | 1.17712 | 1.26175 | 1.34600 |
| 38 | 0.75055 | 0.83671 | 0.92262 | 1.00824 | 1.09355 | 1.17854 | 1.26316 | 1.34740 |
| 39 | 0.75199 | 0.83815 | 0.92405 | 1.00966 | 1.09497 | 1.17995 | 1.26457 | 1.34880 |
| 40 | 0.75343 | 0.83958 | 0.92547 | 1.01109 | 1.09639 | 1.18136 | 1.26598 | 1.35020 |
| 41 | 0.75487 | 0.84101 | 0.92690 | 1.01251 | 1.09781 | 1.18278 | 1.26738 | 1.35160 |
| 42 | 0.75630 | 0.84245 | 0.92833 | 1.01394 | 1.09923 | 1.18419 | 1.26879 | 1.35300 |
| 43 | 0.75774 | 0.84388 | 0.92976 | 1.01536 | 1.10065 | 1.18560 | 1.27020 | 1.35440 |
| 44 | 0.75918 | 0.84531 | 0.93119 | 1.01678 | 1.10207 | 1.18702 | 1.27160 | 1.35580 |
| 45 | 0.76062 | 0.84675 | 0.93262 | 1.01821 | 1.10349 | 1.18843 | 1.27301 | 1.35720 |
| 46 | 0.76205 | 0.84818 | 0.93405 | 1.01963 | 1.10491 | 1.18984 | 1.27442 | 1.35860 |
| 47 | 0.76349 | 0.84961 | 0.93548 | 1.02106 | 1.10632 | 1.19125 | 1.27582 | 1.36000 |
| 48 | 0.76493 | 0.85105 | 0.93691 | 1.02248 | 1.10774 | 1.19267 | 1.27723 | 1.36140 |
| 49 | 0.76637 | 0.85248 | 0.93834 | 1.02390 | 1.10916 | 1.19408 | 1.27863 | 1.36280 |
| 50 | 0.76780 | 0.85391 | 0.93976 | 1.02533 | 1.11058 | 1.19549 | 1.28004 | 1.36420 |
| 51 | 0.76924 | 0.85535 | 0.94119 | 1.02675 | 1.11200 | 1.19690 | 1.28145 | 1.36560 |
| 52 | 0.77068 | 0.85678 | 0.94262 | 1.02817 | 1.11342 | 1.19832 | 1.28285 | 1.36700 |
| 53 | 0.77211 | 0.85821 | 0.94405 | 1.02960 | 1.11483 | 1.19973 | 1.28426 | 1.36840 |
| 54 | 0.77355 | 0.85965 | 0.94548 | 1.03102 | 1.11625 | 1.20114 | 1.28566 | 1.36980 |
| 55 | 0.77499 | 0.86108 | 0.94691 | 1.03244 | 1.11767 | 1.20255 | 1.28707 | 1.37119 |
| 56 | 0.77643 | 0.86251 | 0.94833 | 1.03387 | 1.11909 | 1.20396 | 1.28847 | 1.37259 |
| 57 | 0.77786 | 0.86394 | 0.94976 | 1.03529 | 1.12050 | 1.20538 | 1.28988 | 1.37399 |
| 58 | 0.77930 | 0.86538 | 0.95119 | 1.03671 | 1.12192 | 1.20679 | 1.29129 | 1.37539 |
| 59 | 0.78074 | 0.86681 | 0.95262 | 1.03814 | 1.12334 | 1.20820 | 1.29269 | 1.37679 |
| 60 | 0.78217 | 0.86824 | 0.95404 | 1.03956 | 1.12476 | 1.20961 | 1.29410 | 1.37819 |

Constants for Setting a 5-inch Sine Bar for 16° to 23°

| Min. | 16° | 17° | 18° | 19° | 20° | 21° | 22° | 23° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 1.37819 | 1.46186 | 1.54509 | 1.62784 | 1.71010 | 1.79184 | 1.87303 | 1.95366 |
| 1 | 1.37958 | 1.46325 | 1.54647 | 1.62922 | 1.71147 | 1.79320 | 1.87438 | 1.95499 |
| 2 | 1.38098 | 1.46464 | 1.54785 | 1.63059 | 1.71283 | 1.79456 | 1.87573 | 1.95633 |
| 3 | 1.38238 | 1.46603 | 1.54923 | 1.63197 | 1.71420 | 1.79591 | 1.87708 | 1.95767 |
| 4 | 1.38378 | 1.46742 | 1.55062 | 1.63334 | 1.71557 | 1.79727 | 1.87843 | 1.95901 |
| 5 | 1.38518 | 1.46881 | 1.55200 | 1.63472 | 1.71693 | 1.79863 | 1.87977 | 1.96035 |
| 6 | 1.38657 | 1.47020 | 1.55338 | 1.63609 | 1.71830 | 1.79998 | 1.88112 | 1.96169 |
| 7 | 1.38797 | 1.47159 | 1.55476 | 1.63746 | 1.71966 | 1.80134 | 1.88247 | 1.96302 |
| 8 | 1.38937 | 1.47298 | 1.55615 | 1.63884 | 1.72103 | 1.80270 | 1.88382 | 1.96436 |
| 9 | 1.39076 | 1.47437 | 1.55753 | 1.64021 | 1.72240 | 1.80405 | 1.88516 | 1.96570 |
| 10 | 1.39216 | 1.47576 | 1.55891 | 1.64159 | 1.72376 | 1.80541 | 1.88651 | 1.96704 |
| 11 | 1.39356 | 1.47715 | 1.56029 | 1.64296 | 1.72513 | 1.80677 | 1.88786 | 1.96837 |
| 12 | 1.39496 | 1.47854 | 1.56167 | 1.64433 | 1.72649 | 1.80812 | 1.88920 | 1.96971 |
| 13 | 1.39635 | 1.47993 | 1.56306 | 1.64571 | 1.72786 | 1.80948 | 1.89055 | 1.97105 |
| 14 | 1.39775 | 1.48132 | 1.56444 | 1.64708 | 1.72922 | 1.81083 | 1.89190 | 1.97238 |
| 15 | 1.39915 | 1.48271 | 1.56582 | 1.64845 | 1.73059 | 1.81219 | 1.89324 | 1.97372 |
| 16 | 1.40054 | 1.48410 | 1.56720 | 1.64983 | 1.73195 | 1.81355 | 1.89459 | 1.97506 |
| 17 | 1.40194 | 1.48549 | 1.56858 | 1.65120 | 1.73331 | 1.81490 | 1.89594 | 1.97639 |
| 18 | 1.40333 | 1.48687 | 1.56996 | 1.65257 | 1.73468 | 1.81626 | 1.89728 | 1.97773 |
| 19 | 1.40473 | 1.48826 | 1.57134 | 1.65394 | 1.73604 | 1.81761 | 1.89863 | 1.97906 |
| 20 | 1.40613 | 1.48965 | 1.57272 | 1.65532 | 1.73741 | 1.81897 | 1.89997 | 1.98040 |
| 21 | 1.40752 | 1.49104 | 1.57410 | 1.65669 | 1.73877 | 1.82032 | 1.90132 | 1.98173 |
| 22 | 1.40892 | 1.49243 | 1.57548 | 1.65806 | 1.74013 | 1.82168 | 1.90266 | 1.98307 |
| 23 | 1.41031 | 1.49382 | 1.57687 | 1.65943 | 1.74150 | 1.82303 | 1.90401 | 1.98440 |
| 24 | 1.41171 | 1.49520 | 1.57825 | 1.66081 | 1.74286 | 1.82438 | 1.90535 | 1.98574 |
| 25 | 1.41310 | 1.49659 | 1.57963 | 1.66218 | 1.74422 | 1.82574 | 1.90670 | 1.98707 |
| 26 | 1.41450 | 1.49798 | 1.58101 | 1.66355 | 1.74559 | 1.82709 | 1.90804 | 1.98841 |
| 27 | 1.41589 | 1.49937 | 1.58238 | 1.66492 | 1.74695 | 1.82845 | 1.90939 | 1.98974 |
| 28 | 1.41729 | 1.50075 | 1.58376 | 1.66629 | 1.74831 | 1.82980 | 1.91073 | 1.99108 |
| 29 | 1.41868 | 1.50214 | 1.58514 | 1.66766 | 1.74967 | 1.83115 | 1.91207 | 1.99241 |
| 30 | 1.42008 | 1.50353 | 1.58652 | 1.66903 | 1.75104 | 1.83251 | 1.91342 | 1.99375 |
| 31 | 1.42147 | 1.50492 | 1.58790 | 1.67041 | 1.75240 | 1.83386 | 1.91476 | 1.99508 |
| 32 | 1.42287 | 1.50630 | 1.58928 | 1.67178 | 1.75376 | 1.83521 | 1.91610 | 1.99641 |
| 33 | 1.42426 | 1.50769 | 1.59066 | 1.67315 | 1.75512 | 1.83657 | 1.91745 | 1.99775 |
| 34 | 1.42565 | 1.50908 | 1.59204 | 1.67452 | 1.75649 | 1.83792 | 1.91879 | 1.99908 |
| 35 | 1.42705 | 1.51046 | 1.59342 | 1.67589 | 1.75785 | 1.83927 | 1.92013 | 2.00041 |
| 36 | 1.42844 | 1.51185 | 1.59480 | 1.67726 | 1.75921 | 1.84062 | 1.92148 | 2.00175 |
| 37 | 1.42984 | 1.51324 | 1.59617 | 1.67863 | 1.76057 | 1.84198 | 1.92282 | 2.00308 |
| 38 | 1.43123 | 1.51462 | 1.59755 | 1.68000 | 1.76193 | 1.84333 | 1.92416 | 2.00441 |
| 39 | 1.43262 | 1.51601 | 1.59893 | 1.68137 | 1.76329 | 1.84468 | 1.92550 | 2.00574 |
| 40 | 1.43402 | 1.51739 | 1.60031 | 1.68274 | 1.76465 | 1.84603 | 1.92685 | 2.00708 |
| 41 | 1.43541 | 1.51878 | 1.60169 | 1.68411 | 1.76601 | 1.84738 | 1.92819 | 2.00841 |
| 42 | 1.43680 | 1.52017 | 1.60307 | 1.68548 | 1.76737 | 1.84873 | 1.92953 | 2.00974 |
| 43 | 1.43820 | 1.52155 | 1.60444 | 1.68685 | 1.76873 | 1.85009 | 1.93087 | 2.01107 |
| 44 | 1.43959 | 1.52294 | 1.60582 | 1.68821 | 1.77010 | 1.85144 | 1.93221 | 2.01240 |
| 45 | 1.44098 | 1.52432 | 1.60720 | 1.68958 | 1.77146 | 1.85279 | 1.93355 | 2.01373 |
| 46 | 1.44237 | 1.52571 | 1.60857 | 1.69095 | 1.77282 | 1.85414 | 1.93490 | 2.01506 |
| 47 | 1.44377 | 1.52709 | 1.60995 | 1.69232 | 1.77418 | 1.85549 | 1.93624 | 2.01640 |
| 48 | 1.44516 | 1.52848 | 1.61133 | 1.69369 | 1.77553 | 1.85684 | 1.93758 | 2.01773 |
| 49 | 1.44655 | 1.52986 | 1.61271 | 1.69506 | 1.77689 | 1.85819 | 1.93892 | 2.01906 |
| 50 | 1.44794 | 1.53125 | 1.61408 | 1.69643 | 1.77825 | 1.85954 | 1.94026 | 2.02039 |
| 51 | 1.44934 | 1.53263 | 1.61546 | 1.69779 | 1.77961 | 1.86089 | 1.94160 | 2.02172 |
| 52 | 1.45073 | 1.53401 | 1.61683 | 1.69916 | 1.78097 | 1.86224 | 1.94294 | 2.02305 |
| 53 | 1.45212 | 1.53540 | 1.61821 | 1.70053 | 1.78233 | 1.86359 | 1.94428 | 2.02438 |
| 54 | 1.45351 | 1.53678 | 1.61959 | 1.70190 | 1.78369 | 1.86494 | 1.94562 | 2.02571 |
| 55 | 1.45490 | 1.53817 | 1.62096 | 1.70327 | 1.78505 | 1.86629 | 1.94696 | 2.02704 |
| 56 | 1.45629 | 1.53955 | 1.62234 | 1.70463 | 1.78641 | 1.86764 | 1.94830 | 2.02837 |
| 57 | 1.45769 | 1.54093 | 1.62371 | 1.70600 | 1.78777 | 1.86899 | 1.94964 | 2.02970 |
| 58 | 1.45908 | 1.54232 | 1.62509 | 1.70737 | 1.78912 | 1.87034 | 1.95098 | 2.03103 |
| 59 | 1.46047 | 1.54370 | 1.62647 | 1.70873 | 1.79048 | 1.87168 | 1.95232 | 2.03235 |
| 60 | 1.46186 | 1.54509 | 1.62784 | 1.71010 | 1.79184 | 1.87303 | 1.95366 | 2.03368 |

Constants for Setting a 5-inch Sine Bar for 24° to 31°

| Min. | 24° | 25° | 26° | 27° | 28° | 29° | 30° | 31° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 2.03368 | 2.11309 | 2.19186 | 2.26995 | 2.34736 | 2.42405 | 2.50000 | 2.57519 |
| 1 | 2.03501 | 2.11441 | 2.19316 | 2.27125 | 2.34864 | 2.42532 | 2.50126 | 2.57644 |
| 2 | 2.03634 | 2.11573 | 2.19447 | 2.27254 | 2.34993 | 2.42659 | 2.50252 | 2.57768 |
| 3 | 2.03767 | 2.11704 | 2.19578 | 2.27384 | 2.35121 | 2.42786 | 2.50378 | 2.57893 |
| 4 | 2.03900 | 2.11836 | 2.19708 | 2.27513 | 2.35249 | 2.42913 | 2.50504 | 2.58018 |
| 5 | 2.04032 | 2.11968 | 2.19839 | 2.27643 | 2.35378 | 2.43041 | 2.50630 | 2.58142 |
| 6 | 2.04165 | 2.12100 | 2.19970 | 2.27772 | 2.35506 | 2.43168 | 2.50755 | 2.58267 |
| 7 | 2.04298 | 2.12231 | 2.20100 | 2.27902 | 2.35634 | 2.43295 | 2.50881 | 2.58391 |
| 8 | 2.04431 | 2.12363 | 2.20231 | 2.28031 | 2.35763 | 2.43422 | 2.51007 | 2.58516 |
| 9 | 2.04563 | 2.12495 | 2.20361 | 2.28161 | 2.35891 | 2.43549 | 2.51133 | 2.58640 |
| 10 | 2.04696 | 2.12626 | 2.20492 | 2.28290 | 2.36019 | 2.43676 | 2.51259 | 2.58765 |
| 11 | 2.04829 | 2.12758 | 2.20622 | 2.28420 | 2.36147 | 2.43803 | 2.51384 | 2.58889 |
| 12 | 2.04962 | 2.12890 | 2.20753 | 2.28549 | 2.36275 | 2.43930 | 2.51510 | 2.59014 |
| 13 | 2.05094 | 2.13021 | 2.20883 | 2.28678 | 2.36404 | 2.44057 | 2.51636 | 2.59138 |
| 14 | 2.05227 | 2.13153 | 2.21014 | 2.28808 | 2.36532 | 2.44184 | 2.51761 | 2.59262 |
| 15 | 2.05359 | 2.13284 | 2.21144 | 2.28937 | 2.36660 | 2.44311 | 2.51887 | 2.59387 |
| 16 | 2.05492 | 2.13416 | 2.21275 | 2.29066 | 2.36788 | 2.44438 | 2.52013 | 2.59511 |
| 17 | 2.05625 | 2.13547 | 2.21405 | 2.29196 | 2.36916 | 2.44564 | 2.52138 | 2.59635 |
| 18 | 2.05757 | 2.13679 | 2.21536 | 2.29325 | 2.37044 | 2.44691 | 2.52264 | 2.59760 |
| 19 | 2.05890 | 2.13810 | 2.21666 | 2.29454 | 2.37172 | 2.44818 | 2.52389 | 2.59884 |
| 20 | 2.06022 | 2.13942 | 2.21796 | 2.29583 | 2.37300 | 2.44945 | 2.52515 | 2.60008 |
| 21 | 2.06155 | 2.14073 | 2.21927 | 2.29712 | 2.37428 | 2.45072 | 2.52640 | 2.60132 |
| 22 | 2.06287 | 2.14205 | 2.22057 | 2.29842 | 2.37556 | 2.45198 | 2.52766 | 2.60256 |
| 23 | 2.06420 | 2.14336 | 2.22187 | 2.29971 | 2.37684 | 2.45325 | 2.52891 | 2.60381 |
| 24 | 2.06552 | 2.14468 | 2.22318 | 2.30100 | 2.37812 | 2.45452 | 2.53017 | 2.60505 |
| 25 | 2.06685 | 2.14599 | 2.22448 | 2.30229 | 2.37940 | 2.45579 | 2.53142 | 2.60629 |
| 26 | 2.06817 | 2.14730 | 2.22578 | 2.30358 | 2.38068 | 2.45705 | 2.53268 | 2.60753 |
| 27 | 2.06950 | 2.14862 | 2.22708 | 2.30487 | 2.38196 | 2.45832 | 2.53393 | 2.60877 |
| 28 | 2.07082 | 2.14993 | 2.22839 | 2.30616 | 2.38324 | 2.45959 | 2.53519 | 2.61001 |
| 29 | 2.07214 | 2.15124 | 2.22969 | 2.30745 | 2.38452 | 2.46085 | 2.53644 | 2.61125 |
| 30 | 2.07347 | 2.15256 | 2.23099 | 2.30874 | 2.38579 | 2.46212 | 2.53769 | 2.61249 |
| 31 | 2.07479 | 2.15387 | 2.23229 | 2.31003 | 2.38707 | 2.46338 | 2.53894 | 2.61373 |
| 32 | 2.07611 | 2.15518 | 2.23359 | 2.31132 | 2.38835 | 2.46465 | 2.54020 | 2.61497 |
| 33 | 2.07744 | 2.15649 | 2.23489 | 2.31261 | 2.38963 | 2.46591 | 2.54145 | 2.61621 |
| 34 | 2.07876 | 2.15781 | 2.23619 | 2.31390 | 2.39091 | 2.46718 | 2.54270 | 2.61745 |
| 35 | 2.08008 | 2.15912 | 2.23749 | 2.31519 | 2.39218 | 2.46844 | 2.54396 | 2.61869 |
| 36 | 2.08140 | 2.16043 | 2.23880 | 2.31648 | 2.39346 | 2.46971 | 2.54521 | 2.61993 |
| 37 | 2.08273 | 2.16174 | 2.24010 | 2.31777 | 2.39474 | 2.47097 | 2.54646 | 2.62117 |
| 38 | 2.08405 | 2.16305 | 2.24140 | 2.31906 | 2.39601 | 2.47224 | 2.54771 | 2.62241 |
| 39 | 2.08537 | 2.16436 | 2.24270 | 2.32035 | 2.39729 | 2.47350 | 2.54896 | 2.62364 |
| 40 | 2.08669 | 2.16567 | 2.24400 | 2.32163 | 2.39857 | 2.47477 | 2.55021 | 2.62488 |
| 41 | 2.08801 | 2.16698 | 2.24530 | 2.32292 | 2.39984 | 2.47603 | 2.55146 | 2.62612 |
| 42 | 2.08934 | 2.16830 | 2.24660 | 2.32421 | 2.40112 | 2.47729 | 2.55271 | 2.62736 |
| 43 | 2.09066 | 2.16961 | 2.24789 | 2.32550 | 2.40239 | 2.47856 | 2.55397 | 2.62860 |
| 44 | 2.09198 | 2.17092 | 2.24919 | 2.32679 | 2.40367 | 2.47982 | 2.55522 | 2.62983 |
| 45 | 2.09330 | 2.17223 | 2.25049 | 2.32807 | 2.40494 | 2.48108 | 2.55647 | 2.63107 |
| 46 | 2.09462 | 2.17354 | 2.25179 | 2.32936 | 2.40622 | 2.48235 | 2.55772 | 2.63231 |
| 47 | 2.09594 | 2.17485 | 2.25309 | 2.33065 | 2.40749 | 2.48361 | 2.55896 | 2.63354 |
| 48 | 2.09726 | 2.17616 | 2.25439 | 2.33193 | 2.40877 | 2.48487 | 2.56021 | 2.63478 |
| 49 | 2.09858 | 2.17746 | 2.25569 | 2.33322 | 2.41004 | 2.48613 | 2.56146 | 2.63602 |
| 50 | 2.09990 | 2.17877 | 2.25698 | 2.33451 | 2.41132 | 2.48739 | 2.56271 | 2.63725 |
| 51 | 2.10122 | 2.18008 | 2.25828 | 2.33579 | 2.41259 | 2.48866 | 2.56396 | 2.63849 |
| 52 | 2.10254 | 2.18139 | 2.25958 | 2.33708 | 2.41386 | 2.48992 | 2.56521 | 2.63972 |
| 53 | 2.10386 | 2.18270 | 2.26088 | 2.33836 | 2.41514 | 2.49118 | 2.56646 | 2.64096 |
| 54 | 2.10518 | 2.18401 | 2.26217 | 2.33965 | 2.41641 | 2.49244 | 2.56771 | 2.64219 |
| 55 | 2.10650 | 2.18532 | 2.26347 | 2.34093 | 2.41769 | 2.49370 | 2.56895 | 2.64343 |
| 56 | 2.10782 | 2.18663 | 2.26477 | 2.34222 | 2.41896 | 2.49496 | 2.57020 | 2.64466 |
| 57 | 2.10914 | 2.18793 | 2.26606 | 2.34350 | 2.42023 | 2.49622 | 2.57145 | 2.64590 |
| 58 | 2.11045 | 2.18924 | 2.26736 | 2.34479 | 2.42150 | 2.49748 | 2.57270 | 2.64713 |
| 59 | 2.11177 | 2.19055 | 2.26866 | 2.34607 | 2.42278 | 2.49874 | 2.57394 | 2.64836 |
| 60 | 2.11309 | 2.19186 | 2.26995 | 2.34736 | 2.42405 | 2.50000 | 2.57519 | 2.64960 |

Constants for Setting a 5-inch Sine Bar for 32° to 39°

| Min. | 32° | 33° | 34° | 35° | 36° | 37° | 38° | 39° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 2.64960 | 2.72320 | 2.79596 | 2.86788 | 2.93893 | 3.00908 | 3.07831 | 3.14660 |
| 1 | 2.65083 | 2.72441 | 2.79717 | 2.86907 | 2.94010 | 3.01024 | 3.07945 | 3.14773 |
| 2 | 2.65206 | 2.72563 | 2.79838 | 2.87026 | 2.94128 | 3.01140 | 3.08060 | 3.14886 |
| 3 | 2.65330 | 2.72685 | 2.79958 | 2.87146 | 2.94246 | 3.01256 | 3.08174 | 3.14999 |
| 4 | 2.65453 | 2.72807 | 2.80079 | 2.87265 | 2.94363 | 3.01372 | 3.08289 | 3.15112 |
| 5 | 2.65576 | 2.72929 | 2.80199 | 2.87384 | 2.94481 | 3.01488 | 3.08403 | 3.15225 |
| 6 | 2.65699 | 2.73051 | 2.80319 | 2.87503 | 2.94598 | 3.01604 | 3.08518 | 3.15338 |
| 7 | 2.65822 | 2.73173 | 2.80440 | 2.87622 | 2.94716 | 3.01720 | 3.08632 | 3.15451 |
| 8 | 2.65946 | 2.73295 | 2.80560 | 2.87741 | 2.94833 | 3.01836 | 3.08747 | 3.15564 |
| 9 | 2.66069 | 2.73416 | 2.80681 | 2.87860 | 2.94951 | 3.01952 | 3.08861 | 3.15676 |
| 10 | 2.66192 | 2.73538 | 2.80801 | 2.87978 | 2.95068 | 3.02068 | 3.08976 | 3.15789 |
| 11 | 2.66315 | 2.73660 | 2.80921 | 2.88097 | 2.95185 | 3.02184 | 3.09090 | 3.15902 |
| 12 | 2.66438 | 2.73782 | 2.81042 | 2.88216 | 2.95303 | 3.02300 | 3.09204 | 3.16015 |
| 13 | 2.66561 | 2.73903 | 2.81162 | 2.88335 | 2.95420 | 3.02415 | 3.09318 | 3.16127 |
| 14 | 2.66684 | 2.74025 | 2.81282 | 2.88454 | 2.95538 | 3.02531 | 3.09433 | 3.16240 |
| 15 | 2.66807 | 2.74147 | 2.81402 | 2.88573 | 2.95655 | 3.02647 | 3.09547 | 3.16353 |
| 16 | 2.66930 | 2.74268 | 2.81523 | 2.88691 | 2.95772 | 3.02763 | 3.09661 | 3.16465 |
| 17 | 2.67053 | 2.74390 | 2.81643 | 2.88810 | 2.95889 | 3.02878 | 3.09775 | 3.16578 |
| 18 | 2.67176 | 2.74511 | 2.81763 | 2.88929 | 2.96007 | 3.02994 | 3.09890 | 3.16690 |
| 19 | 2.67299 | 2.74633 | 2.81883 | 2.89048 | 2.96124 | 3.03110 | 3.10004 | 3.16803 |
| 20 | 2.67422 | 2.74754 | 2.82003 | 2.89166 | 2.96241 | 3.03226 | 3.10118 | 3.16915 |
| 21 | 2.67545 | 2.74876 | 2.82123 | 2.89285 | 2.96358 | 3.03341 | 3.10232 | 3.17028 |
| 22 | 2.67668 | 2.74997 | 2.82243 | 2.89403 | 2.96475 | 3.03457 | 3.10346 | 3.17140 |
| 23 | 2.67791 | 2.75119 | 2.82364 | 2.89522 | 2.96592 | 3.03572 | 3.10460 | 3.17253 |
| 24 | 2.67913 | 2.75240 | 2.82484 | 2.89641 | 2.96709 | 3.03688 | 3.10574 | 3.17365 |
| 25 | 2.68036 | 2.75362 | 2.82604 | 2.89759 | 2.96827 | 3.03803 | 3.10688 | 3.17478 |
| 26 | 2.68159 | 2.75483 | 2.82723 | 2.89878 | 2.96944 | 3.03919 | 3.10802 | 3.17590 |
| 27 | 2.68282 | 2.75605 | 2.82843 | 2.89996 | 2.97061 | 3.04034 | 3.10916 | 3.17702 |
| 28 | 2.68404 | 2.75726 | 2.82963 | 2.90115 | 2.97178 | 3.04150 | 3.11030 | 3.17815 |
| 29 | 2.68527 | 2.75847 | 2.83083 | 2.90233 | 2.97294 | 3.04265 | 3.11143 | 3.17927 |
| 30 | 2.68650 | 2.75969 | 2.83203 | 2.90351 | 2.97411 | 3.04381 | 3.11257 | 3.18039 |
| 31 | 2.68772 | 2.76090 | 2.83323 | 2.90470 | 2.97528 | 3.04496 | 3.11371 | 3.18151 |
| 32 | 2.68895 | 2.76211 | 2.83443 | 2.90588 | 2.97645 | 3.04611 | 3.11485 | 3.18264 |
| 33 | 2.69018 | 2.76332 | 2.83563 | 2.90707 | 2.97762 | 3.04727 | 3.11599 | 3.18376 |
| 34 | 2.69140 | 2.76453 | 2.83682 | 2.90825 | 2.97879 | 3.04842 | 3.11712 | 3.18488 |
| 35 | 2.69263 | 2.76575 | 2.83802 | 2.90943 | 2.97996 | 3.04957 | 3.11826 | 3.18600 |
| 36 | 2.69385 | 2.76696 | 2.83922 | 2.91061 | 2.98112 | 3.05073 | 3.11940 | 3.18712 |
| 37 | 2.69508 | 2.76817 | 2.84042 | 2.91180 | 2.98229 | 3.05188 | 3.12053 | 3.18824 |
| 38 | 2.69630 | 2.76938 | 2.84161 | 2.91298 | 2.98346 | 3.05303 | 3.12167 | 3.18936 |
| 39 | 2.69753 | 2.77059 | 2.84281 | 2.91416 | 2.98463 | 3.05418 | 3.12281 | 3.19048 |
| 40 | 2.69875 | 2.77180 | 2.84401 | 2.91534 | 2.98579 | 3.05533 | 3.12394 | 3.19160 |
| 41 | 2.69998 | 2.77301 | 2.84520 | 2.91652 | 2.98696 | 3.05648 | 3.12508 | 3.19272 |
| 42 | 2.70120 | 2.77422 | 2.84640 | 2.91771 | 2.98813 | 3.05764 | 3.12621 | 3.19384 |
| 43 | 2.70243 | 2.77543 | 2.84759 | 2.91889 | 2.98929 | 3.05879 | 3.12735 | 3.19496 |
| 44 | 2.70365 | 2.77664 | 2.84879 | 2.92007 | 2.99046 | 3.05994 | 3.12848 | 3.19608 |
| 45 | 2.70487 | 2.77785 | 2.84998 | 2.92125 | 2.99162 | 3.06109 | 3.12962 | 3.19720 |
| 46 | 2.70610 | 2.77906 | 2.85118 | 2.92243 | 2.99279 | 3.06224 | 3.13075 | 3.19831 |
| 47 | 2.70732 | 2.78027 | 2.85237 | 2.92361 | 2.99395 | 3.06339 | 3.13189 | 3.19943 |
| 48 | 2.70854 | 2.78148 | 2.85357 | 2.92479 | 2.99512 | 3.06454 | 3.13302 | 3.20055 |
| 49 | 2.70976 | 2.78269 | 2.85476 | 2.92597 | 2.99628 | 3.06568 | 3.13415 | 3.20167 |
| 50 | 2.71099 | 2.78389 | 2.85596 | 2.92715 | 2.99745 | 3.06683 | 3.13529 | 3.20278 |
| 51 | 2.71221 | 2.78510 | 2.85715 | 2.92833 | 2.99861 | 3.06798 | 3.13642 | 3.20390 |
| 52 | 2.71343 | 2.78631 | 2.85834 | 2.92950 | 2.99977 | 3.06913 | 3.13755 | 3.20502 |
| 53 | 2.71465 | 2.78752 | 2.85954 | 2.93068 | 3.00094 | 3.07028 | 3.13868 | 3.20613 |
| 54 | 2.71587 | 2.78873 | 2.86073 | 2.93186 | 3.00210 | 3.07143 | 3.13982 | 3.20725 |
| 55 | 2.71709 | 2.78993 | 2.86192 | 2.93304 | 3.00326 | 3.07257 | 3.14095 | 3.20836 |
| 56 | 2.71831 | 2.79114 | 2.86311 | 2.93422 | 3.00443 | 3.07372 | 3.14208 | 3.20948 |
| 57 | 2.71953 | 2.79235 | 2.86431 | 2.93540 | 3.00559 | 3.07487 | 3.14321 | 3.21059 |
| 58 | 2.72076 | 2.79355 | 2.86550 | 2.93657 | 3.00675 | 3.07601 | 3.14434 | 3.21171 |
| 59 | 2.72198 | 2.79476 | 2.86669 | 2.93775 | 3.00791 | 3.07716 | 3.14547 | 3.21282 |
| 60 | 2.72320 | 2.79596 | 2.86788 | 2.93893 | 3.00908 | 3.07831 | 3.14660 | 3.21394 |

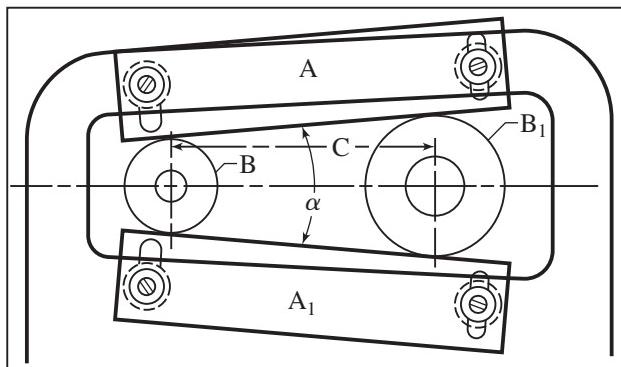
Constants for Setting a 5-inch Sine Bar for 40° to 47°

| Min. | 40° | 41° | 42° | 43° | 44° | 45° | 46° | 47° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 3.21394 | 3.28030 | 3.34565 | 3.40999 | 3.47329 | 3.53553 | 3.59670 | 3.65677 |
| 1 | 3.21505 | 3.28139 | 3.34673 | 3.41106 | 3.47434 | 3.53656 | 3.59771 | 3.65776 |
| 2 | 3.21617 | 3.28249 | 3.34781 | 3.41212 | 3.47538 | 3.53759 | 3.59872 | 3.65875 |
| 3 | 3.21728 | 3.28359 | 3.34889 | 3.41318 | 3.47643 | 3.53862 | 3.59973 | 3.65974 |
| 4 | 3.21839 | 3.28468 | 3.34997 | 3.41424 | 3.47747 | 3.53965 | 3.60074 | 3.66073 |
| 5 | 3.21951 | 3.28578 | 3.35105 | 3.41531 | 3.47852 | 3.54067 | 3.60175 | 3.66172 |
| 6 | 3.22062 | 3.28688 | 3.35213 | 3.41637 | 3.47956 | 3.54170 | 3.60276 | 3.66271 |
| 7 | 3.22173 | 3.28797 | 3.35321 | 3.41743 | 3.48061 | 3.54273 | 3.60376 | 3.66370 |
| 8 | 3.22284 | 3.28907 | 3.35429 | 3.41849 | 3.48165 | 3.54375 | 3.60477 | 3.66469 |
| 9 | 3.22395 | 3.29016 | 3.35537 | 3.41955 | 3.48270 | 3.54478 | 3.60578 | 3.66568 |
| 10 | 3.22507 | 3.29126 | 3.35645 | 3.42061 | 3.48374 | 3.54580 | 3.60679 | 3.66667 |
| 11 | 3.22618 | 3.29235 | 3.35753 | 3.42168 | 3.48478 | 3.54683 | 3.60779 | 3.66766 |
| 12 | 3.22729 | 3.29345 | 3.35860 | 3.42274 | 3.48583 | 3.54785 | 3.60880 | 3.66865 |
| 13 | 3.22840 | 3.29454 | 3.35968 | 3.42380 | 3.48687 | 3.54888 | 3.60981 | 3.66964 |
| 14 | 3.22951 | 3.29564 | 3.36076 | 3.42486 | 3.48791 | 3.54990 | 3.61081 | 3.67063 |
| 15 | 3.23062 | 3.29673 | 3.36183 | 3.42592 | 3.48895 | 3.55093 | 3.61182 | 3.67161 |
| 16 | 3.23173 | 3.29782 | 3.36291 | 3.42697 | 3.48999 | 3.55195 | 3.61283 | 3.67260 |
| 17 | 3.23284 | 3.29892 | 3.36399 | 3.42803 | 3.49104 | 3.55297 | 3.61383 | 3.67359 |
| 18 | 3.23395 | 3.30001 | 3.36506 | 3.42909 | 3.49208 | 3.55400 | 3.61484 | 3.67457 |
| 19 | 3.23506 | 3.30110 | 3.36614 | 3.43015 | 3.49312 | 3.55502 | 3.61584 | 3.67556 |
| 20 | 3.23617 | 3.30219 | 3.36721 | 3.43121 | 3.49416 | 3.55604 | 3.61684 | 3.67655 |
| 21 | 3.23728 | 3.30329 | 3.36829 | 3.43227 | 3.49520 | 3.55707 | 3.61785 | 3.67753 |
| 22 | 3.23838 | 3.30438 | 3.36936 | 3.43332 | 3.49624 | 3.55809 | 3.61885 | 3.67852 |
| 23 | 3.23949 | 3.30547 | 3.37044 | 3.43438 | 3.49728 | 3.55911 | 3.61986 | 3.67950 |
| 24 | 3.24060 | 3.30656 | 3.37151 | 3.43544 | 3.49832 | 3.56013 | 3.62086 | 3.68049 |
| 25 | 3.24171 | 3.30765 | 3.37259 | 3.43649 | 3.49936 | 3.56115 | 3.62186 | 3.68147 |
| 26 | 3.24281 | 3.30874 | 3.37366 | 3.43755 | 3.50039 | 3.56217 | 3.62286 | 3.68245 |
| 27 | 3.24392 | 3.30983 | 3.37473 | 3.43861 | 3.50143 | 3.56319 | 3.62387 | 3.68344 |
| 28 | 3.24503 | 3.31092 | 3.37581 | 3.43966 | 3.50247 | 3.56421 | 3.62487 | 3.68442 |
| 29 | 3.24613 | 3.31201 | 3.37688 | 3.44072 | 3.50351 | 3.56523 | 3.62587 | 3.68540 |
| 30 | 3.24724 | 3.31310 | 3.37795 | 3.44177 | 3.50455 | 3.56625 | 3.62687 | 3.68639 |
| 31 | 3.24835 | 3.31419 | 3.37902 | 3.44283 | 3.50558 | 3.56727 | 3.62787 | 3.68737 |
| 32 | 3.24945 | 3.31528 | 3.38010 | 3.44388 | 3.50662 | 3.56829 | 3.62887 | 3.68835 |
| 33 | 3.25056 | 3.31637 | 3.38117 | 3.44494 | 3.50766 | 3.56931 | 3.62987 | 3.68933 |
| 34 | 3.25166 | 3.31746 | 3.38224 | 3.44599 | 3.50869 | 3.57033 | 3.63087 | 3.69031 |
| 35 | 3.25277 | 3.31854 | 3.38331 | 3.44704 | 3.50973 | 3.57135 | 3.63187 | 3.69130 |
| 36 | 3.25387 | 3.31963 | 3.38438 | 3.44810 | 3.51077 | 3.57236 | 3.63287 | 3.69228 |
| 37 | 3.25498 | 3.32072 | 3.38545 | 3.44915 | 3.51180 | 3.57338 | 3.63387 | 3.69326 |
| 38 | 3.25608 | 3.32181 | 3.38652 | 3.45020 | 3.51284 | 3.57440 | 3.63487 | 3.69424 |
| 39 | 3.25718 | 3.32289 | 3.38759 | 3.45126 | 3.51387 | 3.57542 | 3.63587 | 3.69522 |
| 40 | 3.25829 | 3.32398 | 3.38866 | 3.45231 | 3.51491 | 3.57643 | 3.63687 | 3.69620 |
| 41 | 3.25939 | 3.32507 | 3.38973 | 3.45336 | 3.51594 | 3.57745 | 3.63787 | 3.69718 |
| 42 | 3.26049 | 3.32615 | 3.39080 | 3.45441 | 3.51697 | 3.57846 | 3.63886 | 3.69816 |
| 43 | 3.26159 | 3.32724 | 3.39187 | 3.45546 | 3.51801 | 3.57948 | 3.63986 | 3.69913 |
| 44 | 3.26270 | 3.32832 | 3.39294 | 3.45651 | 3.51904 | 3.58049 | 3.64086 | 3.70011 |
| 45 | 3.26380 | 3.32941 | 3.39400 | 3.45757 | 3.52007 | 3.58151 | 3.64186 | 3.70109 |
| 46 | 3.26490 | 3.33049 | 3.39507 | 3.45862 | 3.52111 | 3.58252 | 3.64285 | 3.70207 |
| 47 | 3.26600 | 3.33158 | 3.39614 | 3.45967 | 3.52214 | 3.58354 | 3.64385 | 3.70305 |
| 48 | 3.26710 | 3.33266 | 3.39721 | 3.46072 | 3.52317 | 3.58455 | 3.64484 | 3.70402 |
| 49 | 3.26820 | 3.33375 | 3.39827 | 3.46177 | 3.52420 | 3.58557 | 3.64584 | 3.70500 |
| 50 | 3.26930 | 3.33483 | 3.39934 | 3.46281 | 3.52523 | 3.58658 | 3.64683 | 3.70598 |
| 51 | 3.27040 | 3.33591 | 3.40041 | 3.46386 | 3.52627 | 3.58759 | 3.64783 | 3.70695 |
| 52 | 3.27150 | 3.33700 | 3.40147 | 3.46491 | 3.52730 | 3.58861 | 3.64882 | 3.70793 |
| 53 | 3.27260 | 3.33808 | 3.40254 | 3.46596 | 3.52833 | 3.58962 | 3.64982 | 3.70890 |
| 54 | 3.27370 | 3.33916 | 3.40360 | 3.46701 | 3.52936 | 3.59063 | 3.65081 | 3.70988 |
| 55 | 3.27480 | 3.34025 | 3.40467 | 3.46806 | 3.53039 | 3.59164 | 3.65181 | 3.71085 |
| 56 | 3.27590 | 3.34133 | 3.40573 | 3.46910 | 3.53142 | 3.59266 | 3.65280 | 3.71183 |
| 57 | 3.27700 | 3.34241 | 3.40680 | 3.47015 | 3.53245 | 3.59367 | 3.65379 | 3.71280 |
| 58 | 3.27810 | 3.34349 | 3.40786 | 3.47120 | 3.53348 | 3.59468 | 3.65478 | 3.71378 |
| 59 | 3.27920 | 3.34457 | 3.40893 | 3.47225 | 3.53451 | 3.59569 | 3.65578 | 3.71475 |
| 60 | 3.28030 | 3.34565 | 3.40999 | 3.47329 | 3.53553 | 3.59670 | 3.65677 | 3.71572 |

Constants for Setting a 5-inch Sine Bar for 48° to 55°

| Min. | 48° | 49° | 50° | 51° | 52° | 53° | 54° | 55° |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0 | 3.71572 | 3.77355 | 3.83022 | 3.88573 | 3.94005 | 3.99318 | 4.04508 | 4.09576 |
| 1 | 3.71670 | 3.77450 | 3.83116 | 3.88665 | 3.94095 | 3.99405 | 4.04594 | 4.09659 |
| 2 | 3.71767 | 3.77546 | 3.83209 | 3.88756 | 3.94184 | 3.99493 | 4.04679 | 4.09743 |
| 3 | 3.71864 | 3.77641 | 3.83303 | 3.88847 | 3.94274 | 3.99580 | 4.04765 | 4.09826 |
| 4 | 3.71961 | 3.77736 | 3.83396 | 3.88939 | 3.94363 | 3.99668 | 4.04850 | 4.09909 |
| 5 | 3.72059 | 3.77831 | 3.83489 | 3.89030 | 3.94453 | 3.99755 | 4.04936 | 4.09993 |
| 6 | 3.72156 | 3.77927 | 3.83583 | 3.89122 | 3.94542 | 3.99842 | 4.05021 | 4.10076 |
| 7 | 3.72253 | 3.78022 | 3.83676 | 3.89213 | 3.94631 | 3.99930 | 4.05106 | 4.10159 |
| 8 | 3.72350 | 3.78117 | 3.83769 | 3.89304 | 3.94721 | 4.00017 | 4.05191 | 4.10242 |
| 9 | 3.72447 | 3.78212 | 3.83862 | 3.89395 | 3.94810 | 4.00104 | 4.05277 | 4.10325 |
| 10 | 3.72544 | 3.78307 | 3.83956 | 3.89487 | 3.94899 | 4.00191 | 4.05362 | 4.10409 |
| 11 | 3.72641 | 3.78402 | 3.84049 | 3.89578 | 3.94988 | 4.00279 | 4.05447 | 4.10492 |
| 12 | 3.72738 | 3.78498 | 3.84142 | 3.89669 | 3.95078 | 4.00366 | 4.05532 | 4.10575 |
| 13 | 3.72835 | 3.78593 | 3.84235 | 3.89760 | 3.95167 | 4.00453 | 4.05617 | 4.10658 |
| 14 | 3.72932 | 3.78688 | 3.84328 | 3.89851 | 3.95256 | 4.00540 | 4.05702 | 4.10741 |
| 15 | 3.73029 | 3.78783 | 3.84421 | 3.89942 | 3.95345 | 4.00627 | 4.05787 | 4.10823 |
| 16 | 3.73126 | 3.78877 | 3.84514 | 3.90033 | 3.95434 | 4.00714 | 4.05872 | 4.10906 |
| 17 | 3.73222 | 3.78972 | 3.84607 | 3.90124 | 3.95523 | 4.00801 | 4.05957 | 4.10989 |
| 18 | 3.73319 | 3.79067 | 3.84700 | 3.90215 | 3.95612 | 4.00888 | 4.06042 | 4.11072 |
| 19 | 3.73416 | 3.79162 | 3.84793 | 3.90306 | 3.95701 | 4.00975 | 4.06127 | 4.11155 |
| 20 | 3.73513 | 3.79257 | 3.84886 | 3.90397 | 3.95790 | 4.01062 | 4.06211 | 4.11238 |
| 21 | 3.73609 | 3.79352 | 3.84978 | 3.90488 | 3.95878 | 4.01148 | 4.06296 | 4.11320 |
| 22 | 3.73706 | 3.79446 | 3.85071 | 3.90579 | 3.95967 | 4.01235 | 4.06381 | 4.11403 |
| 23 | 3.73802 | 3.79541 | 3.85164 | 3.90669 | 3.96056 | 4.01322 | 4.06466 | 4.11486 |
| 24 | 3.73899 | 3.79636 | 3.85257 | 3.90760 | 3.96145 | 4.01409 | 4.06550 | 4.11568 |
| 25 | 3.73996 | 3.79730 | 3.85349 | 3.90851 | 3.96234 | 4.01495 | 4.06635 | 4.11651 |
| 26 | 3.74092 | 3.79825 | 3.85442 | 3.90942 | 3.96322 | 4.01582 | 4.06720 | 4.11733 |
| 27 | 3.74189 | 3.79919 | 3.85535 | 3.91032 | 3.96411 | 4.01669 | 4.06804 | 4.11816 |
| 28 | 3.74285 | 3.80014 | 3.85627 | 3.91123 | 3.96500 | 4.01755 | 4.06889 | 4.11898 |
| 29 | 3.74381 | 3.80109 | 3.85720 | 3.91214 | 3.96588 | 4.01842 | 4.06973 | 4.11981 |
| 30 | 3.74478 | 3.80203 | 3.85812 | 3.91304 | 3.96677 | 4.01928 | 4.07058 | 4.12063 |
| 31 | 3.74574 | 3.80297 | 3.85905 | 3.91395 | 3.96765 | 4.02015 | 4.07142 | 4.12145 |
| 32 | 3.74671 | 3.80392 | 3.85997 | 3.91485 | 3.96854 | 4.02101 | 4.07227 | 4.12228 |
| 33 | 3.74767 | 3.80486 | 3.86090 | 3.91576 | 3.96942 | 4.02188 | 4.07311 | 4.12310 |
| 34 | 3.74863 | 3.80581 | 3.86182 | 3.91666 | 3.97031 | 4.02274 | 4.07395 | 4.12392 |
| 35 | 3.74959 | 3.80675 | 3.86274 | 3.91756 | 3.97119 | 4.02361 | 4.07480 | 4.12475 |
| 36 | 3.75056 | 3.80769 | 3.86367 | 3.91847 | 3.97207 | 4.02447 | 4.07564 | 4.12557 |
| 37 | 3.75152 | 3.80863 | 3.86459 | 3.91937 | 3.97296 | 4.02533 | 4.07648 | 4.12639 |
| 38 | 3.75248 | 3.80958 | 3.86551 | 3.92027 | 3.97384 | 4.02619 | 4.07732 | 4.12721 |
| 39 | 3.75344 | 3.81052 | 3.86644 | 3.92118 | 3.97472 | 4.02706 | 4.07817 | 4.12803 |
| 40 | 3.75440 | 3.81146 | 3.86736 | 3.92208 | 3.97560 | 4.02792 | 4.07901 | 4.12885 |
| 41 | 3.75536 | 3.81240 | 3.86828 | 3.92298 | 3.97649 | 4.02878 | 4.07985 | 4.12967 |
| 42 | 3.75632 | 3.81334 | 3.86920 | 3.92388 | 3.97737 | 4.02964 | 4.08069 | 4.13049 |
| 43 | 3.75728 | 3.81428 | 3.87012 | 3.92478 | 3.97825 | 4.03050 | 4.08153 | 4.13131 |
| 44 | 3.75824 | 3.81522 | 3.87104 | 3.92568 | 3.97913 | 4.03136 | 4.08237 | 4.13213 |
| 45 | 3.75920 | 3.81616 | 3.87196 | 3.92658 | 3.98001 | 4.03222 | 4.08321 | 4.13295 |
| 46 | 3.76016 | 3.81710 | 3.87288 | 3.92748 | 3.98089 | 4.03308 | 4.08405 | 4.13377 |
| 47 | 3.76112 | 3.81804 | 3.87380 | 3.92839 | 3.98177 | 4.03394 | 4.08489 | 4.13459 |
| 48 | 3.76207 | 3.81898 | 3.87472 | 3.92928 | 3.98265 | 4.03480 | 4.08572 | 4.13540 |
| 49 | 3.76303 | 3.81992 | 3.87564 | 3.93018 | 3.98353 | 4.03566 | 4.08656 | 4.13622 |
| 50 | 3.76399 | 3.82086 | 3.87656 | 3.93108 | 3.98441 | 4.03652 | 4.08740 | 4.13704 |
| 51 | 3.76495 | 3.82179 | 3.87748 | 3.93198 | 3.98529 | 4.03738 | 4.08824 | 4.13785 |
| 52 | 3.76590 | 3.82273 | 3.87840 | 3.93288 | 3.98616 | 4.03823 | 4.08908 | 4.13867 |
| 53 | 3.76686 | 3.82367 | 3.87931 | 3.93378 | 3.98704 | 4.03909 | 4.08991 | 4.13949 |
| 54 | 3.76782 | 3.82461 | 3.88023 | 3.93468 | 3.98792 | 4.03995 | 4.09075 | 4.14030 |
| 55 | 3.76877 | 3.82554 | 3.88115 | 3.93557 | 3.98880 | 4.04081 | 4.09158 | 4.14112 |
| 56 | 3.76973 | 3.82648 | 3.88207 | 3.93647 | 3.98967 | 4.04166 | 4.09242 | 4.14193 |
| 57 | 3.77068 | 3.82742 | 3.88298 | 3.93737 | 3.99055 | 4.04252 | 4.09326 | 4.14275 |
| 58 | 3.77164 | 3.82835 | 3.88390 | 3.93826 | 3.99143 | 4.04337 | 4.09409 | 4.14356 |
| 59 | 3.77259 | 3.82929 | 3.88481 | 3.93916 | 3.99230 | 4.04423 | 4.09493 | 4.14437 |
| 60 | 3.77355 | 3.83022 | 3.88573 | 3.94005 | 3.99318 | 4.04508 | 4.09576 | 4.14519 |

Accurate Measurement of Angles and Tapers.— When great accuracy is required in the measurement of angles, or when originating tapers, disks are commonly used. The principle of the disk method of taper measurement is that if two disks of unequal diameters are placed either in contact or a certain distance apart, lines tangent to their peripheries will represent an angle or taper, the degree of which depends upon the diameters of the two disks and the distance between them.



The gage shown in the accompanying illustration, which is a form commonly used for originating tapers or measuring angles accurately, is set by means of disks. This gage consists of two adjustable straight edges A and A_1 , which are in contact with disks B and B_1 . The angle α or the taper between the straight edges depends, of course, upon the diameters of the disks and the center distance C , and as these three dimensions can be measured accurately, it is possible to set the gage to a given angle within very close limits. Moreover, if a record of the three dimensions is kept, the exact setting of the gage can be reproduced quickly at any time. The following rules may be used for adjusting a gage of this type, and cover all problems likely to arise in practice. Disks are also occasionally used for the setting of parts in angular positions when they are to be machined accurately to a given angle: the rules are applicable to these conditions also.

Rules for Figuring Tapers

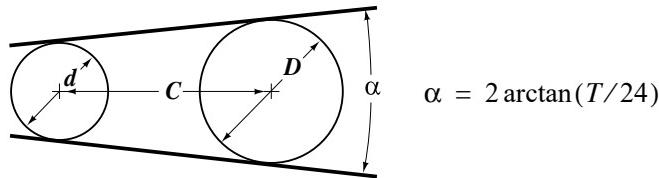
| Given | To Find | Rule |
|--|---|---|
| The taper per foot. The taper per inch. End diameters and length of taper in inches. | The taper per inch. The taper per foot. The taper per foot. | Divide the taper per foot by 12. Multiply the taper per inch by 12. Subtract small diameter from large; divide by length of taper; and multiply quotient by 12. |
| Large diameter and length of taper in inches, and taper per foot. | Diameter at small end in inches | Divide taper per foot by 12; multiply by length of taper; and subtract result from large diameter. |
| Small diameter and length of taper in inches, and taper per foot. | Diameter at large end in inches. | Divide taper per foot by 12; multiply by length of taper; and add result to small diameter. |
| The taper per foot and two diameters in inches. | Distance between two given diameters in inches. | Subtract small diameter from large; divide remainder by taper per foot; and multiply quotient by 12. |
| The taper per foot. | Amount of taper in a certain length in inches. | Divide taper per foot by 12; multiply by given length of tapered part. |

TAPERS

Tapers per Foot and Corresponding Angles

| Taper per Foot | Included Angle | Angle with Center Line | Taper per Foot | Included Angle | Angle with Center Line |
|------------------|----------------|------------------------|------------------|----------------|------------------------|
| $\frac{1}{64}$ | 0° 4' 29" | 0° 2' 14" | $1\frac{1}{8}$ | 8° 56' 4" | 4° 28' 2" |
| $\frac{1}{32}$ | 0 8 57 | 0 4 29 | $1\frac{15}{16}$ | 9 13 51 | 4 36 56 |
| $\frac{1}{16}$ | 0 17 54 | 0 8 57 | 2 | 9 31 38 | 4 45 49 |
| $\frac{3}{32}$ | 0 26 51 | 0 13 26 | $2\frac{1}{8}$ | 10 7 11 | 5 3 36 |
| $\frac{1}{8}$ | 0 35 49 | 0 17 54 | $2\frac{1}{4}$ | 10 42 42 | 5 21 21 |
| $\frac{5}{32}$ | 0 44 46 | 0 22 23 | $2\frac{3}{8}$ | 11 18 11 | 5 39 5 |
| $\frac{3}{16}$ | 0 53 43 | 0 26 51 | $2\frac{1}{2}$ | 11 53 37 | 5 56 49 |
| $\frac{7}{32}$ | 1 2 40 | 0 31 20 | $2\frac{5}{8}$ | 12 29 2 | 6 14 31 |
| $\frac{1}{4}$ | 1 11 37 | 0 35 49 | $2\frac{3}{4}$ | 13 4 24 | 6 32 12 |
| $\frac{9}{32}$ | 1 20 34 | 0 40 17 | $2\frac{7}{8}$ | 13 39 43 | 6 49 52 |
| $\frac{5}{16}$ | 1 29 31 | 0 44 46 | 3 | 14 15 0 | 7 7 30 |
| $1\frac{1}{32}$ | 1 38 28 | 0 49 14 | $3\frac{1}{8}$ | 14 50 14 | 7 25 7 |
| $\frac{3}{8}$ | 1 47 25 | 0 53 43 | $3\frac{1}{4}$ | 15 25 26 | 7 42 43 |
| $1\frac{3}{32}$ | 1 56 22 | 0 58 11 | $3\frac{3}{8}$ | 16 0 34 | 8 0 17 |
| $\frac{7}{16}$ | 2 5 19 | 1 2 40 | $3\frac{1}{2}$ | 16 35 39 | 8 17 50 |
| $1\frac{5}{32}$ | 2 14 16 | 1 7 8 | $3\frac{5}{8}$ | 17 10 42 | 8 35 21 |
| $\frac{1}{2}$ | 2 23 13 | 1 11 37 | $3\frac{3}{4}$ | 17 45 41 | 8 52 50 |
| $1\frac{7}{32}$ | 2 32 10 | 1 16 5 | $3\frac{7}{8}$ | 18 20 36 | 9 10 18 |
| $\frac{9}{16}$ | 2 41 7 | 1 20 33 | 4 | 18 55 29 | 9 27 44 |
| $1\frac{9}{32}$ | 2 50 4 | 1 25 2 | $4\frac{1}{8}$ | 19 30 17 | 9 45 9 |
| $\frac{5}{8}$ | 2 59 1 | 1 29 30 | $4\frac{1}{4}$ | 20 5 3 | 10 2 31 |
| $2\frac{1}{32}$ | 3 7 57 | 1 33 59 | $4\frac{3}{8}$ | 20 39 44 | 10 19 52 |
| $1\frac{11}{32}$ | 3 16 54 | 1 38 27 | $4\frac{1}{2}$ | 21 14 22 | 10 37 11 |
| $2\frac{3}{32}$ | 3 25 51 | 1 42 55 | $4\frac{5}{8}$ | 21 48 55 | 10 54 28 |
| $\frac{3}{4}$ | 3 34 47 | 1 47 24 | $4\frac{3}{4}$ | 22 23 25 | 11 11 42 |
| $2\frac{5}{32}$ | 3 43 44 | 1 51 52 | $4\frac{7}{8}$ | 22 57 50 | 11 28 55 |
| $1\frac{13}{32}$ | 3 52 41 | 1 56 20 | 5 | 23 32 12 | 11 46 6 |
| $2\frac{7}{32}$ | 4 1 37 | 2 0 49 | $5\frac{1}{8}$ | 24 6 29 | 12 3 14 |
| $\frac{7}{8}$ | 4 10 33 | 2 5 17 | $5\frac{1}{4}$ | 24 40 41 | 12 20 21 |
| $2\frac{9}{32}$ | 4 19 30 | 2 9 45 | $5\frac{3}{8}$ | 25 14 50 | 12 37 25 |
| $1\frac{15}{32}$ | 4 28 26 | 2 14 13 | $5\frac{1}{2}$ | 25 48 53 | 12 54 27 |
| $3\frac{1}{32}$ | 4 37 23 | 2 18 41 | $5\frac{5}{8}$ | 26 22 52 | 13 11 26 |
| 1 | 4 46 19 | 2 23 9 | $5\frac{3}{4}$ | 26 56 47 | 13 28 23 |
| $1\frac{1}{16}$ | 5 4 11 | 2 32 6 | $5\frac{7}{8}$ | 27 30 36 | 13 45 18 |
| $1\frac{1}{8}$ | 5 22 3 | 2 41 2 | 6 | 28 4 21 | 14 2 10 |
| $1\frac{3}{16}$ | 5 39 55 | 2 49 57 | $6\frac{1}{8}$ | 28 38 1 | 14 19 0 |
| $1\frac{1}{4}$ | 5 57 47 | 2 58 53 | $6\frac{1}{4}$ | 29 11 35 | 14 35 48 |
| $1\frac{5}{16}$ | 6 15 38 | 3 7 49 | $6\frac{3}{8}$ | 29 45 5 | 14 52 32 |
| $1\frac{3}{8}$ | 6 33 29 | 3 16 44 | $6\frac{1}{2}$ | 30 18 29 | 15 9 15 |
| $1\frac{7}{16}$ | 6 51 19 | 3 25 40 | $6\frac{5}{8}$ | 30 51 48 | 15 25 54 |
| $1\frac{1}{2}$ | 7 9 10 | 3 34 35 | $6\frac{3}{4}$ | 31 25 2 | 15 42 31 |
| $1\frac{1}{16}$ | 7 27 0 | 3 43 30 | $6\frac{7}{8}$ | 31 58 11 | 15 59 5 |
| $1\frac{1}{8}$ | 7 44 49 | 3 52 25 | 7 | 32 31 13 | 16 15 37 |
| $1\frac{11}{16}$ | 8 2 38 | 4 1 19 | $7\frac{1}{8}$ | 33 4 11 | 16 32 5 |
| $1\frac{3}{4}$ | 8 20 27 | 4 10 14 | $7\frac{1}{4}$ | 33 37 3 | 16 48 31 |
| $1\frac{13}{16}$ | 8 38 16 | 4 19 8 | $7\frac{3}{8}$ | 34 9 49 | 17 4 54 |

To find angle α for given taper T in inches per foot.—



$$\alpha = 2 \arctan(T/24)$$

To find taper T given angle α in degrees.—

$$T = 24 \tan(\alpha/2) \text{ inches per foot}$$

To find angle α given dimensions D, d , and C .— Let K be the difference in the disk diameters divided by twice the center distance. $K = (D-d)/(2C)$, then $\alpha = 2 \arcsin K$

To find taper T measured at right angles to a line through the disk centers given dimensions D, d , and distance C .— Find K using the formula in the previous example, then $T = 24K/\sqrt{1-K^2}$ inches per foot

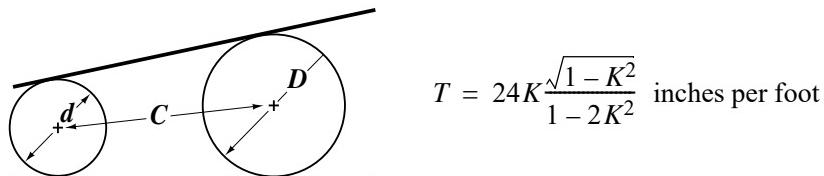
To find center distance C for a given taper T in inches per foot.—

$$C = \frac{D-d}{2} \times \frac{\sqrt{1+(T/24)^2}}{T/24} \text{ inches}$$

To find center distance C for a given angle α and dimensions D and d .—

$$C = (D-d)/2 \sin(\alpha/2) \text{ inches}$$

To find taper T measured at right angles to one side .— When one side is taken as a base line and the taper is measured at right angles to that side, calculate K as explained above and use the following formula for determining the taper T :

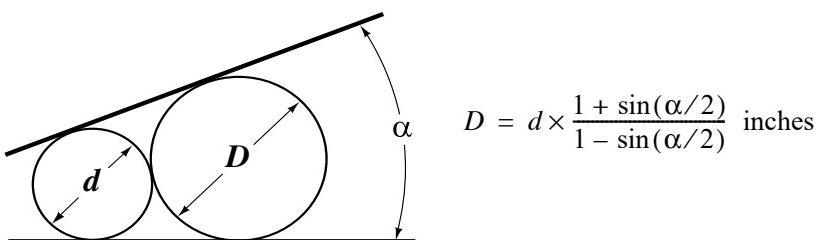


$$T = 24K \frac{\sqrt{1-K^2}}{1-2K^2} \text{ inches per foot}$$

To find center distance C when taper T is measured from one side.—

$$C = \frac{D-d}{\sqrt{2-2/\sqrt{1+(T/12)^2}}} \text{ inches}$$

To find diameter D of a large disk in contact with a small disk of diameter d given angle α .—



$$D = d \times \frac{1 + \sin(\alpha/2)}{1 - \sin(\alpha/2)} \text{ inches}$$

Gage Block Sets—Inch Sizes Federal Specification GGG-G-15C

| Set Number 1 (81 Blocks) | | | | | | | | | |
|--|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| First Series: 0.0001 Inch Increments (9 Blocks) | | | | | | | | | |
| 0.1001 | 0.1002 | 0.1003 | 0.1004 | 0.1005 | 0.1006 | 0.1007 | 0.1008 | 0.1009 | |
| Second Series: 0.001 Inch Increments (49 Blocks) | | | | | | | | | |
| 0.101 | 0.102 | 0.103 | 0.104 | 0.105 | 0.106 | 0.107 | 0.108 | 0.109 | 0.110 |
| 0.111 | 0.112 | 0.113 | 0.114 | 0.115 | 0.116 | 0.117 | 0.118 | 0.119 | 0.120 |
| 0.121 | 0.122 | 0.123 | 0.124 | 0.125 | 0.126 | 0.127 | 0.128 | 0.129 | 0.130 |
| 0.131 | 0.132 | 0.133 | 0.134 | 0.135 | 0.136 | 0.137 | 0.138 | 0.139 | 0.140 |
| 0.141 | 0.142 | 0.143 | 0.144 | 0.145 | 0.146 | 0.147 | 0.148 | 0.149 | |
| Third Series: 0.050 Inch Increments (19 Blocks) | | | | | | | | | |
| 0.050 | 0.100 | 0.150 | 0.200 | 0.250 | 0.300 | 0.350 | 0.400 | 0.450 | 0.500 |
| 0.550 | 0.600 | 0.650 | 0.700 | 0.750 | 0.800 | 0.850 | 0.900 | 0.950 | |
| Fourth Series: 1.000 Inch Increments (4 Blocks) | | | | | | | | | |
| 1.000 | | | 2.000 | | | 3.000 | | | 4.000 |

Set number 4 is not shown, and the Specification does not list a set 2 or 3.

Arranged here in incremental series for convenience of use.

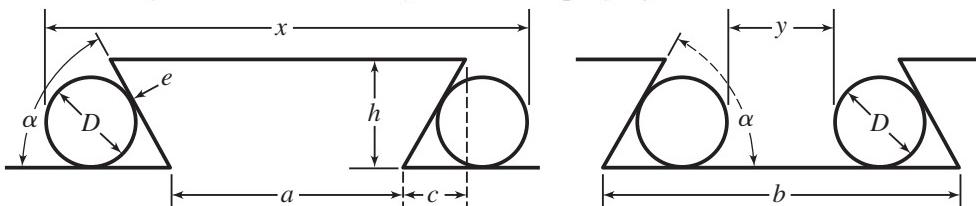
Example, Making a Gage Block Stack: Determine the blocks required to obtain a dimension of 3.6742 inch

- 1) Use the fewest numbers of blocks for a given dimension, otherwise the chance of error can be increased by the wringing interval between blocks.
- 2) Block selection is based on successively eliminating the right-hand figure of the desired dimension.
- 3) Stacks can be constructed with or without wear blocks.

$$\begin{array}{r}
 3.6742 \\
 -0.100 \quad \text{Subtract 0.100 for the two 0.050 wear blocks} \\
 \hline
 3.5742 \\
 -0.1002 \quad \text{Eliminate the 0.0002 with the 0.1002 block from the first series and subtract} \\
 \hline
 3.4740 \\
 -0.124 \quad \text{Eliminate the 0.004 with the 0.124 block from the second series and subtract} \\
 \hline
 3.3500 \\
 -0.350 \quad \text{Eliminate the 0.350 with the 0.350 block from the third series and eliminate the} \\
 \hline
 -3.0000 \quad \text{3.000 with the 3.0000 block from the fourth series and subtract} \\
 \hline
 0.0000
 \end{array}$$

The combined blocks are: 2 0.050 wear blocks
 1 0.124 block
 1 0.350 block
 1 3.0000 block

Measuring Dovetail Slides.—Dovetail slides that must be machined accurately to a given width are commonly gaged by using pieces of cylindrical rod or wire and measuring as indicated by the dimensions x and y of the accompanying illustrations.



To obtain dimension x for measuring male dovetails, add 1 to the cotangent of one-half the dovetail angle α , multiply by diameter D of the rods used, and add the product to dimension α . To obtain dimension y for measuring a female dovetail, add 1 to the cotangent of one-half the dovetail angle α , multiply by diameter D of the rod used, and subtract the result from dimension b . Expressing these rules as formulas:

$$x = D(1 + \cot \frac{1}{2}\alpha) + a$$

$$y = b - D(1 + \cot \frac{1}{2}\alpha)$$

$$c = h \times \cot \alpha$$

The rod or wire used should be small enough so that the point of contact e is somewhat below the corner or edge of the dovetail.

Checking a V-shaped Groove by Measurement Over Pins.—In checking a groove of the shape shown in Fig. 5, it is necessary to measure the dimension X over the pins of radius R . If values for the radius R , dimension Z , and the angles α and β are known, the problem is to determine the distance Y , to arrive at the required overall dimension for X . If a line AC is drawn from the bottom of the V to the center of the pin at the left in Fig. 5, and a line CB from the center of this pin to its point of tangency with the side of the V, a right-angled triangle is formed in which one side, CB , is known and one angle CAB , can be determined. A line drawn from the center of a circle to the point of intersection of two tangents to the circle bisects the angle made by the tangent lines, and angle CAB therefore equals $\frac{1}{2}(\alpha + \beta)$. The length AC and the angle DAC can now be found, and with AC known in the right-angled triangle ADC, AD , which is equal to Y , can be found.

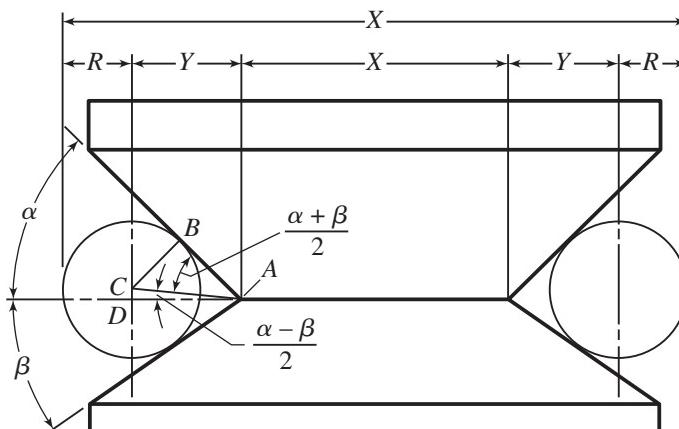


Fig. 5.

The value for X can be obtained from the formula

$$X = Z + 2R \left(\csc \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2} + 1 \right)$$

For example, if $R = 0.500$, $Z = 1.824$, $\alpha = 45$ degrees, and $\beta = 35$ degrees,

$$X = 1.824 + (2 \times 0.5) \left(\csc \frac{45^\circ + 35^\circ}{2} \cos \frac{45^\circ - 35^\circ}{2} + 1 \right)$$

$$X = 1.824 + \csc 40^\circ \cos 5^\circ + 1$$

$$X = 1.824 + 1.5557 \times 0.99619 + 1$$

$$X = 1.824 + 1.550 + 1 = 4.374$$

Diameters of Wires for Measuring American Standard and British Standard Whitworth Screw Threads

| Threads per Inch | Pitch, Inch | Wire Diameters for American Standard Threads | | | Wire Diameters for Whitworth Standard Threads | | |
|------------------|-------------|--|--------|--------------------|---|--------|--------------------|
| | | Max. | Min. | Pitch Line Contact | Max. | Min. | Pitch Line Contact |
| 4 | 0.2500 | 0.2250 | 0.1400 | 0.1443 | 0.1900 | 0.1350 | 0.1409 |
| 4½ | 0.2222 | 0.2000 | 0.1244 | 0.1283 | 0.1689 | 0.1200 | 0.1253 |
| 5 | 0.2000 | 0.1800 | 0.1120 | 0.1155 | 0.1520 | 0.1080 | 0.1127 |
| 5½ | 0.1818 | 0.1636 | 0.1018 | 0.1050 | 0.1382 | 0.0982 | 0.1025 |
| 6 | 0.1667 | 0.1500 | 0.0933 | 0.0962 | 0.1267 | 0.0900 | 0.0939 |
| 7 | 0.1428 | 0.1283 | 0.0800 | 0.0825 | 0.1086 | 0.0771 | 0.0805 |
| 8 | 0.1250 | 0.1125 | 0.0700 | 0.0722 | 0.0950 | 0.0675 | 0.0705 |
| 9 | 0.1111 | 0.1000 | 0.0622 | 0.0641 | 0.0844 | 0.0600 | 0.0626 |
| 10 | 0.1000 | 0.0900 | 0.0560 | 0.0577 | 0.0760 | 0.0540 | 0.0564 |
| 11 | 0.0909 | 0.0818 | 0.0509 | 0.0525 | 0.0691 | 0.0491 | 0.0512 |
| 12 | 0.0833 | 0.0750 | 0.0467 | 0.0481 | 0.0633 | 0.0450 | 0.0470 |
| 13 | 0.0769 | 0.0692 | 0.0431 | 0.0444 | 0.0585 | 0.0415 | 0.0434 |
| 14 | 0.0714 | 0.0643 | 0.0400 | 0.0412 | 0.0543 | 0.0386 | 0.0403 |
| 16 | 0.0625 | 0.0562 | 0.0350 | 0.0361 | 0.0475 | 0.0337 | 0.0352 |
| 18 | 0.0555 | 0.0500 | 0.0311 | 0.0321 | 0.0422 | 0.0300 | 0.0313 |
| 20 | 0.0500 | 0.0450 | 0.0280 | 0.0289 | 0.0380 | 0.0270 | 0.0282 |
| 22 | 0.0454 | 0.0409 | 0.0254 | 0.0262 | 0.0345 | 0.0245 | 0.0256 |
| 24 | 0.0417 | 0.0375 | 0.0233 | 0.0240 | 0.0317 | 0.0225 | 0.0235 |
| 28 | 0.0357 | 0.0321 | 0.0200 | 0.0206 | 0.0271 | 0.0193 | 0.0201 |
| 32 | 0.0312 | 0.0281 | 0.0175 | 0.0180 | 0.0237 | 0.0169 | 0.0176 |
| 36 | 0.0278 | 0.0250 | 0.0156 | 0.0160 | 0.0211 | 0.0150 | 0.0156 |
| 40 | 0.0250 | 0.0225 | 0.0140 | 0.0144 | 0.0190 | 0.0135 | 0.0141 |

Notation Used in Formulas for Checking Pitch Diameters by Three-Wire Method

A = one-half included thread angle in the axial plane

A_n = one-half included thread angle in the normal plane or in plane perpendicular to sides of thread
= one-half included angle of cutter when thread is milled ($\tan A_n = \tan A \times \cos B$).

(Note: Included angle of milling cutter or grinding wheel may equal the nominal included angle of thread, or may be reduced to whatever normal angle is required to make the thread angle standard in the axial plane. In either case, A_n = one-half cutter angle.)

B = lead angle at pitch diameter = helix angle of thread as measured from a plane perpendicular to the axis. $\tan B = L \div 3.1416E$

D = basic major or outside diameter

E = pitch diameter (basic, maximum, or minimum) for which *M* is required, or pitch diameter corresponding to measurement *M*

H = helix angle at pitch diameter and measured from axis = $90^\circ - B$ or $\tan H = \cot B$

H_b = helix angle at *R_b* measured from axis

L = lead of thread = pitch *P* \times number of threads *S*

M = dimension over wires

P = pitch = $1 \div$ number of threads per inch

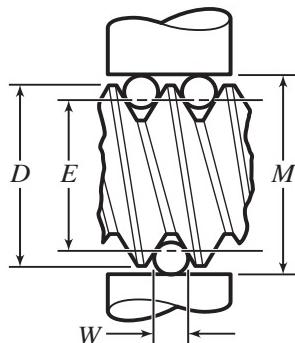
S = number of “starts” or threads on a multiple-threaded worm or screw

T = $0.5 P$ = width of thread in axial plane at diameter *E*

T_a = arc thickness on pitch cylinder in plane perpendicular to axis

W = wire or pin diameter

Formulas for Checking Pitch Diameters of Screw Threads



The formulas below do not compensate for the effect of the lead angle upon measurement M , but they are sufficiently accurate for checking standard single-thread screws unless exceptional accuracy is required. See accompanying information on effect of lead angle; also matter relating to measuring wire sizes, accuracy required for such wires, and contact or measuring pressure. The approximate best wire size for pitch-line contact may be obtained by the formula

$$W = 0.5 \times \text{pitch} \times \sec \frac{1}{2} \text{ included thread angle}$$

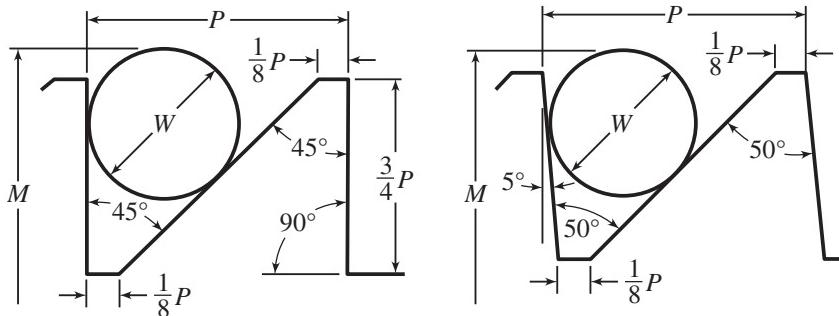
For 60-degree threads, $W = 0.57735 \times \text{pitch}$.

| Form of Thread | Formulas for determining measurement M corresponding to correct pitch diameter and the pitch diameter E corresponding to a given measurement over wires. ^a |
|------------------------------------|---|
| American National Standard Unified | When measurement M is known. $E = M + 0.86603P - 3W$ When pitch diameter E is used in formula. $M = E - 0.86603P + 3W$ The American Standard formerly was known as U.S. Standard. |
| British Standard Whitworth | When measurement M is known. $E = M + 0.9605P - 3.1657W$ When pitch diameter E is used in formula. $M = E - 0.9605P + 3.1657W$ |
| British Association Standard | When measurement M is known. $E = M + 1.1363P - 3.4829W$ When pitch diameter E is used in formula. $M = E - 1.1363P + 3.4829W$ |
| Lowenherz Thread | When measurement M is known. $E = M + P - 3.2359W$ When pitch diameter E is used in formula. $M = E - P + 3.2359W$ |
| Sharp V-Thread | When measurement M is known. $E = M + 0.86603P - 3W$ When pitch diameter E is used in formula. $M = E - 0.86603P + 3W$ |
| International Standard | Use the formula given above for the American National Standard Unified Thread. |
| Buttress Form of Thread | Various forms of buttress threads are used. See paragraph on <i>Three-Wire Method Applied to Buttress Threads</i> , on page 42 |

^aThe wires must be lapped to a uniform diameter and it is very important to insert in the rule or formula the wire diameter as determined by precise means of measurement. Any error will be multiplied. See paragraph on Wire Sizes for Checking Pitch Diameters.

Three-Wire Method Applied to Buttress Threads.—The angles of buttress threads vary somewhat, especially on the front or load-resisting side. Formula (1), which follows, may be applied to any angles required. In this formula, M = measurement over wires when pitch diameter E is correct; A = included angle of thread and thread groove; a = angle of front face or load-resisting side, measured from a line perpendicular to screw thread axis; P = pitch of thread; and W = wire diameter.

$$M = E - \left[\frac{P}{\tan a + \tan(A-a)} \right] + W \left[1 + \cos\left(\frac{A}{2} - a\right) \times \csc\frac{A}{2} \right] \quad (1)$$



For given angles A and a , this general formula may be simplified as shown by Formulas (3) and (4). These simplified formulas contain constants with values depending upon angles A and a .

Wire Diameter: The wire diameter for obtaining pitch-line contact at the back of a buttress thread may be determined by the following general Formula (2):

$$W = P \left(\frac{\cos a}{1 + \cos A} \right) \quad (2)$$

45-Degree Buttress Thread: The buttress thread shown by the diagram at the left, has a front or load-resisting side that is perpendicular to the axis of the screw. Measurement M equivalent to a correct pitch diameter E may be determined by Formula (3):

$$M = E - P + (W \times 3.4142) \quad (3)$$

Wire diameter W for pitch-line contact at back of thread = $0.586 \times$ pitch.

50-Degree Buttress Thread with Front-face Inclination of 5 Degrees: This buttress thread form is illustrated by the diagram at the right. Measurement M equivalent to the correct pitch diameter E may be determined by Formula (4):

$$M = E - (P \times 0.91955) + (W \times 3.2235) \quad (4)$$

Wire diameter W for pitch-line contact at back of thread = $0.606 \times$ pitch. If the width of flat at crest and root = $\frac{1}{8} \times$ pitch, depth = $0.69 \times$ pitch.

American National Standard Buttress Threads ANSI B1.9-1973: This buttress screw thread has an included thread angle of 52 degrees and a front face inclination of 7 degrees. Measurements M equivalent to a pitch diameter E may be determined by Formula (5):

$$M = E - 0.89064P + 3.15689W + c \quad (5)$$

The wire angle correction factor c is less than 0.0004 inch for recommended combinations of thread diameters and pitches and may be neglected. Use of wire diameter $W = 0.54147P$ is recommended.

Constants Used in Formulas for Measuring the Pitch Diameters of Inch Screws by the Three-wire System

| No. of Threads per Inch | American Standard Unified and Sharp V-Thread 0.86603P | Whitworth Thread 0.9605P | No. of Threads per Inch | American Standard Unified and Sharp V-Thread 0.86603P | Whitworth Thread 0.9605P |
|-------------------------|---|--------------------------|-------------------------|---|--------------------------|
| 2½ | 0.38490 | 0.42689 | 18 | 0.04811 | 0.05336 |
| 2¾ | 0.36464 | 0.40442 | 20 | 0.04330 | 0.04803 |
| 2½ | 0.34641 | 0.38420 | 22 | 0.03936 | 0.04366 |
| 2½ | 0.32992 | 0.36590 | 24 | 0.03608 | 0.04002 |
| 2¾ | 0.31492 | 0.34927 | 26 | 0.03331 | 0.03694 |
| 2¾ | 0.30123 | 0.33409 | 28 | 0.03093 | 0.03430 |
| 3 | 0.28868 | 0.32017 | 30 | 0.02887 | 0.03202 |
| 3¼ | 0.26647 | 0.29554 | 32 | 0.02706 | 0.03002 |
| 3½ | 0.24744 | 0.27443 | 34 | 0.02547 | 0.02825 |
| 4 | 0.21651 | 0.24013 | 36 | 0.02406 | 0.02668 |
| 4½ | 0.19245 | 0.21344 | 38 | 0.02279 | 0.02528 |
| 5 | 0.17321 | 0.19210 | 40 | 0.02165 | 0.02401 |
| 5½ | 0.15746 | 0.17464 | 42 | 0.02062 | 0.02287 |
| 6 | 0.14434 | 0.16008 | 44 | 0.01968 | 0.02183 |
| 7 | 0.12372 | 0.13721 | 46 | 0.01883 | 0.02088 |
| 8 | 0.10825 | 0.12006 | 48 | 0.01804 | 0.02001 |
| 9 | 0.09623 | 0.10672 | 50 | 0.01732 | 0.01921 |
| 10 | 0.08660 | 0.09605 | 52 | 0.01665 | 0.01847 |
| 11 | 0.07873 | 0.08732 | 56 | 0.01546 | 0.01715 |
| 12 | 0.07217 | 0.08004 | 60 | 0.01443 | 0.01601 |
| 13 | 0.06662 | 0.07388 | 64 | 0.01353 | 0.01501 |
| 14 | 0.06186 | 0.06861 | 68 | 0.01274 | 0.01412 |
| 15 | 0.05774 | 0.06403 | 72 | 0.01203 | 0.01334 |
| 16 | 0.05413 | 0.06003 | 80 | 0.01083 | 0.01201 |

Constants Used for Measuring Pitch Diameters of Metric Screws by the Three-wire System

| Pitch in mm | 0.86603P in Inches | W in Inches | Pitch in mm | 0.86603P in Inches | W in Inches | Pitch in mm | 0.86603P in Inches | W in Inches |
|-------------|--------------------|-------------|-------------|--------------------|-------------|-------------|--------------------|-------------|
| 0.2 | 0.00682 | 0.00455 | 0.75 | 0.02557 | 0.01705 | 3.5 | 0.11933 | 0.07956 |
| 0.25 | 0.00852 | 0.00568 | 0.8 | 0.02728 | 0.01818 | 4 | 0.13638 | 0.09092 |
| 0.3 | 0.01023 | 0.00682 | 1 | 0.03410 | 0.02273 | 4.5 | 0.15343 | 0.10229 |
| 0.35 | 0.01193 | 0.00796 | 1.25 | 0.04262 | 0.02841 | 5 | 0.17048 | 0.11365 |
| 0.4 | 0.01364 | 0.00909 | 1.5 | 0.05114 | 0.03410 | 5.5 | 0.18753 | 0.12502 |
| 0.45 | 0.01534 | 0.01023 | 1.75 | 0.05967 | 0.03978 | 6 | 0.20457 | 0.13638 |
| 0.5 | 0.01705 | 0.01137 | 2 | 0.06819 | 0.04546 | 8 | 0.30686 | 0.18184 |
| 0.6 | 0.02046 | 0.01364 | 2.5 | 0.08524 | 0.05683 | ... | ... | ... |
| 0.7 | 0.02387 | 0.01591 | 3 | 0.10229 | 0.06819 | ... | ... | ... |

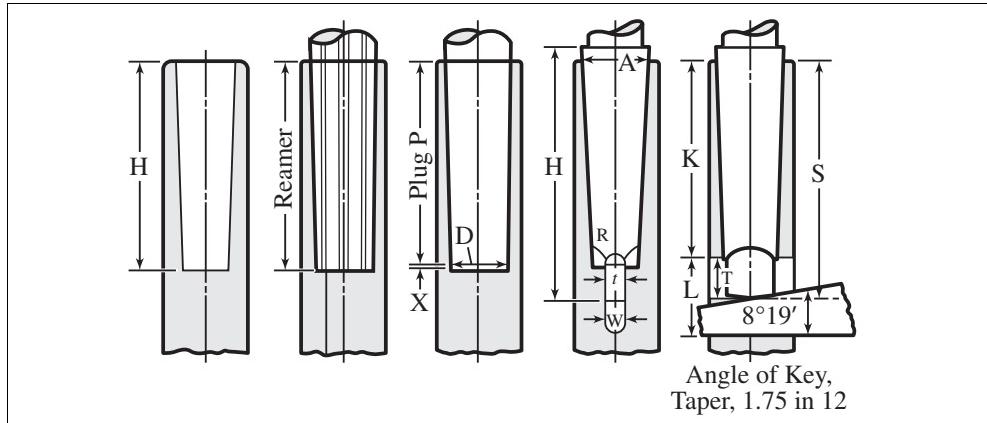
This table may be used for American National Standard Metric Threads. The formulas for American Standard Unified Threads on page 41 are used. In the table above, the values of 0.86603P and W are in inches so that the values for E and M calculated from the formulas on page 41 are also in inches.

STANDARD TAPERS

Morse Taper

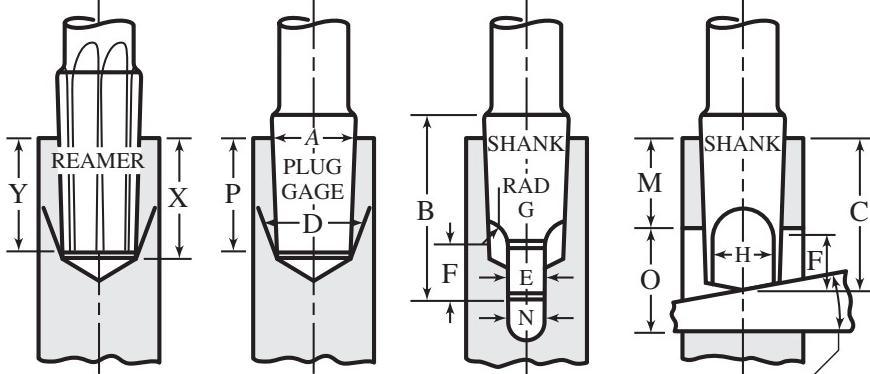
Morse Taper.—Dimensions relating to Morse standard taper shanks and sockets may be found in an accompanying table. The taper for different numbers of Morse tapers is slightly different, but it is approximately $\frac{5}{8}$ inch per foot in most cases. The table gives the actual tapers, accurate to five decimal places. Morse taper shanks are used on a variety of tools, and exclusively on the shanks of twist drills.

Table 1. Morse Standard Taper Shanks



| No. of Taper | Taper per Foot | Taper per Inch | Small End of Plug D | Diameter End of Socket A | Shank | | Depth of Hole H |
|-----------------|----------------|----------------|-----------------------|----------------------------|-----------------|------------------|-------------------|
| | | | | | Length B | Depth S | |
| 0 | 0.62460 | 0.05205 | 0.252 | 0.3561 | $2\frac{1}{32}$ | $2\frac{7}{32}$ | $2\frac{1}{32}$ |
| 1 | 0.59858 | 0.04988 | 0.369 | 0.475 | $2\frac{7}{16}$ | $2\frac{7}{16}$ | $2\frac{5}{32}$ |
| 2 | 0.59941 | 0.04995 | 0.572 | 0.700 | $3\frac{1}{8}$ | $2\frac{15}{16}$ | $2\frac{39}{64}$ |
| 3 | 0.60235 | 0.05019 | 0.778 | 0.938 | $3\frac{7}{8}$ | $3\frac{11}{16}$ | $3\frac{1}{4}$ |
| 4 | 0.62326 | 0.05193 | 1.020 | 1.231 | $4\frac{7}{8}$ | $4\frac{5}{8}$ | $4\frac{1}{8}$ |
| 5 | 0.63151 | 0.05262 | 1.475 | 1.748 | $6\frac{1}{8}$ | $5\frac{7}{8}$ | $5\frac{1}{4}$ |
| 6 | 0.62565 | 0.05213 | 2.116 | 2.494 | $8\frac{9}{16}$ | $8\frac{1}{4}$ | $7\frac{21}{64}$ |
| 7 | 0.62400 | 0.05200 | 2.750 | 3.270 | $11\frac{5}{8}$ | $11\frac{1}{4}$ | $10\frac{5}{64}$ |
| Plug Depth P | Tang or Tongue | | | | Keyway | | Keyway to End K |
| | Thickness t | Length T | Radius R | Diameter | Width W | Length L | |
| 2 | 0.1562 | $\frac{1}{4}$ | $\frac{5}{32}$ | 0.235 | $1\frac{1}{64}$ | $\frac{1}{16}$ | $1\frac{15}{16}$ |
| $2\frac{1}{8}$ | 0.2031 | $\frac{3}{8}$ | $\frac{3}{16}$ | 0.343 | 0.218 | $\frac{3}{4}$ | $2\frac{1}{16}$ |
| $2\frac{7}{16}$ | 0.2500 | $\frac{7}{16}$ | $\frac{1}{4}$ | $1\frac{17}{32}$ | 0.266 | $\frac{7}{8}$ | $2\frac{1}{2}$ |
| $3\frac{3}{16}$ | 0.3125 | $\frac{9}{16}$ | $\frac{9}{32}$ | $2\frac{23}{32}$ | 0.328 | $1\frac{13}{16}$ | $3\frac{1}{16}$ |
| $4\frac{1}{16}$ | 0.4687 | $\frac{5}{8}$ | $\frac{5}{16}$ | $3\frac{1}{32}$ | 0.484 | $1\frac{1}{4}$ | $3\frac{7}{8}$ |
| $5\frac{3}{16}$ | 0.6250 | $\frac{3}{4}$ | $\frac{3}{8}$ | $1\frac{13}{32}$ | 0.656 | $1\frac{1}{2}$ | $4\frac{15}{16}$ |
| $7\frac{1}{4}$ | 0.7500 | $1\frac{1}{8}$ | $\frac{1}{2}$ | 2 | 0.781 | $1\frac{1}{4}$ | 7 |
| 10 | 1.1250 | $1\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{5}{8}$ | 1.156 | $2\frac{5}{8}$ | $9\frac{1}{2}$ |

Table 2. Morse Stub Taper Shanks



TAPER 1 3/4" PER FOOT

| No. of Taper | Taper per Foot ^a | Taper per Inch ^b | Small End of Plug, ^b <i>D</i> | Dia. End of Socket, ^a <i>A</i> | Shank | | Tang | |
|--------------------|-----------------------------------|-----------------------------------|---|--|------------------------------|---|-----------------------------|---------------------|
| | | | | | Total Length, <i>B</i> | Depth, <i>C</i> | Thick- ness, <i>E</i> | Length, <i>F</i> |
| 1 | 0.59858 | 0.049882 | 0.4314 | 0.475 | 1 $\frac{5}{16}$ | 1 $\frac{1}{8}$ | $\frac{13}{64}$ | $\frac{5}{16}$ |
| 2 | 0.59941 | 0.049951 | 0.6469 | 0.700 | 1 $\frac{11}{16}$ | 1 $\frac{7}{16}$ | $\frac{19}{64}$ | $\frac{7}{16}$ |
| 3 | 0.60235 | 0.050196 | 0.8753 | 0.938 | 2 | 1 $\frac{3}{4}$ | $\frac{25}{64}$ | $\frac{9}{16}$ |
| 4 | 0.62326 | 0.051938 | 1.1563 | 1.231 | 2 $\frac{3}{8}$ | 2 $\frac{1}{16}$ | $\frac{33}{64}$ | $\frac{11}{16}$ |
| 5 | 0.63151 | 0.052626 | 1.6526 | 1.748 | 3 | 2 $\frac{11}{16}$ | $\frac{3}{4}$ | $\frac{15}{16}$ |
| No. of Taper | Tang | | Socket | | | Tang Slot | | |
| | Radius of Mill, <i>G</i> | Dia- meter, <i>H</i> | Plug Depth, <i>P</i> | Min. Depth of Tapered Hole | | Socket End to Tang Slot, <i>M</i> | Width, <i>N</i> | Length, <i>O</i> |
| 1 | $\frac{3}{16}$ | $1\frac{13}{32}$ | | $\frac{7}{8}$ | $\frac{5}{16}$ | $2\frac{9}{32}$ | $\frac{25}{32}$ | $\frac{7}{32}$ |
| 2 | $\frac{7}{32}$ | $\frac{39}{64}$ | | $1\frac{1}{16}$ | $1\frac{5}{32}$ | $1\frac{7}{64}$ | $1\frac{5}{16}$ | $\frac{5}{16}$ |
| 3 | $\frac{9}{32}$ | $1\frac{13}{16}$ | | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{5}{16}$ | $1\frac{1}{16}$ | $1\frac{13}{32}$ |
| 4 | $\frac{3}{8}$ | $1\frac{3}{32}$ | | $1\frac{7}{16}$ | $1\frac{9}{16}$ | $1\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{17}{32}$ |
| 5 | $\frac{9}{16}$ | $1\frac{19}{32}$ | | $1\frac{13}{16}$ | $1\frac{15}{16}$ | $1\frac{7}{8}$ | $1\frac{7}{16}$ | $2\frac{5}{32}$ |

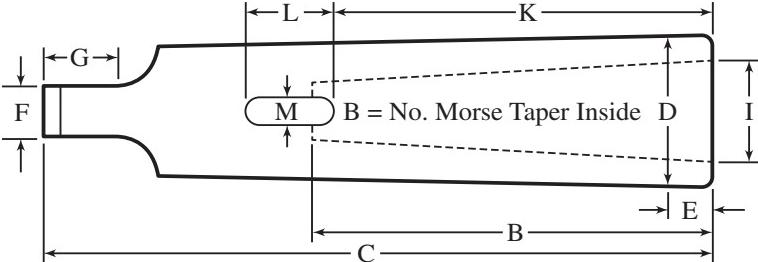
All dimensions in inches.

Radius *J* is $\frac{3}{64}$, $\frac{1}{16}$, $\frac{5}{64}$, $\frac{3}{32}$, and $\frac{1}{8}$ inch respectively for Nos. 1, 2, 3, 4, and 5 tapers.

^aThese are basic dimensions.

^bThese dimensions are calculated for reference only.

Table 3. Dimensions of Morse Taper Sleeves

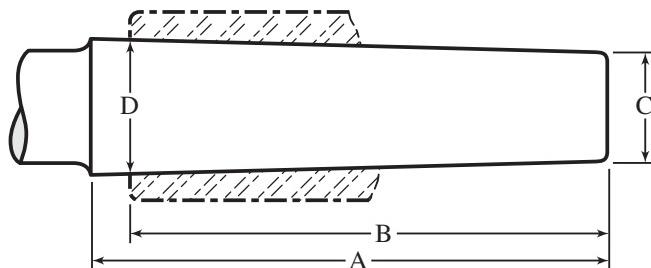


The diagram illustrates the cross-section of a Morse Taper Sleeve. It features a stepped profile with a large outer diameter (A) and a smaller inner diameter (B). Key dimensions labeled include: F (width of the shoulder), G (width of the taper face), L (width of the neck), K (total length of the shank), D (inner diameter at the neck), I (outer diameter at the neck), E (width of the shoulder at the neck), C (width of the shoulder at the small end), and M (inner diameter at the small end).

| A | B | C | D | E | F | G | H | I | K | L | M |
|---|---|-------------------|-------|----------------|-----------------|----------------|-----------------|-------|------------------|-----------------|-------|
| 2 | 1 | 3 $\frac{3}{16}$ | 0.700 | $\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{7}{16}$ | $2\frac{3}{16}$ | 0.475 | $2\frac{1}{16}$ | $\frac{3}{4}$ | 0.213 |
| 3 | 1 | 3 $\frac{15}{16}$ | 0.938 | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{9}{16}$ | $2\frac{3}{16}$ | 0.475 | $2\frac{1}{16}$ | $\frac{3}{4}$ | 0.213 |
| 3 | 2 | 4 $\frac{7}{16}$ | 0.938 | $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{9}{16}$ | $2\frac{5}{8}$ | 0.700 | $2\frac{1}{2}$ | $\frac{7}{8}$ | 0.260 |
| 4 | 1 | 4 $\frac{7}{8}$ | 1.231 | $\frac{1}{4}$ | $1\frac{5}{32}$ | $\frac{5}{8}$ | $2\frac{3}{16}$ | 0.475 | $2\frac{1}{16}$ | $\frac{3}{4}$ | 0.213 |
| 4 | 2 | 4 $\frac{7}{8}$ | 1.231 | $\frac{1}{4}$ | $1\frac{5}{32}$ | $\frac{5}{8}$ | $2\frac{5}{8}$ | 0.700 | $2\frac{1}{2}$ | $\frac{7}{8}$ | 0.260 |
| 4 | 3 | 5 $\frac{3}{8}$ | 1.231 | $\frac{3}{4}$ | $1\frac{5}{32}$ | $\frac{5}{8}$ | $3\frac{1}{4}$ | 0.938 | $3\frac{1}{16}$ | $1\frac{3}{16}$ | 0.322 |
| 5 | 1 | 6 $\frac{1}{8}$ | 1.748 | $\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $2\frac{3}{16}$ | 0.475 | $2\frac{1}{16}$ | $\frac{3}{4}$ | 0.213 |
| 5 | 2 | 6 $\frac{1}{8}$ | 1.748 | $\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $2\frac{5}{8}$ | 0.700 | $2\frac{1}{2}$ | $\frac{7}{8}$ | 0.260 |
| 5 | 3 | 6 $\frac{1}{8}$ | 1.748 | $\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $3\frac{1}{4}$ | 0.938 | $3\frac{1}{16}$ | $1\frac{3}{16}$ | 0.322 |
| 5 | 4 | 6 $\frac{5}{8}$ | 1.748 | $\frac{3}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $4\frac{1}{8}$ | 1.231 | $3\frac{7}{8}$ | $1\frac{1}{4}$ | 0.478 |
| 6 | 1 | 8 $\frac{5}{8}$ | 2.494 | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $2\frac{3}{16}$ | 0.475 | $2\frac{1}{16}$ | $\frac{3}{4}$ | 0.213 |
| 6 | 2 | 8 $\frac{5}{8}$ | 2.494 | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $2\frac{5}{8}$ | 0.700 | $2\frac{1}{2}$ | $\frac{7}{8}$ | 0.260 |
| 6 | 3 | 8 $\frac{5}{8}$ | 2.494 | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $3\frac{1}{4}$ | 0.938 | $3\frac{1}{16}$ | $1\frac{3}{16}$ | 0.322 |
| 6 | 4 | 8 $\frac{5}{8}$ | 2.494 | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $4\frac{1}{8}$ | 1.231 | $3\frac{7}{8}$ | $1\frac{1}{4}$ | 0.478 |
| 6 | 5 | 8 $\frac{5}{8}$ | 2.494 | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $5\frac{1}{4}$ | 1.748 | $4\frac{15}{16}$ | $1\frac{1}{2}$ | 0.635 |
| 7 | 3 | 11 $\frac{5}{8}$ | 3.270 | $\frac{3}{8}$ | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{4}$ | 0.938 | $3\frac{1}{16}$ | $1\frac{3}{16}$ | 0.322 |
| 7 | 4 | 11 $\frac{5}{8}$ | 3.270 | $\frac{3}{8}$ | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $4\frac{1}{8}$ | 1.231 | $3\frac{7}{8}$ | $1\frac{1}{4}$ | 0.478 |
| 7 | 5 | 11 $\frac{5}{8}$ | 3.270 | $\frac{3}{8}$ | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $5\frac{1}{4}$ | 1.748 | $4\frac{15}{16}$ | $1\frac{1}{2}$ | 0.635 |
| 7 | 6 | 12 $\frac{1}{2}$ | 3.270 | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $7\frac{1}{8}$ | 2.494 | 7 | $1\frac{1}{4}$ | 0.760 |

Jarno Taper.—The Jarno taper was originally proposed by Oscar J. Beale of the Brown & Sharpe Mfg. Co. This taper is based on such simple formulas that practically no calculations are required when the number of taper is known. The taper per foot of all Jarno taper sizes is 0.600 inch on the diameter. The diameter at the large end is as many eighths, the diameter at the small end is as many tenths, and the length as many half inches as are indicated by the number of the taper. For example, a No. 7 Jarno taper is $\frac{7}{8}$ inch in diameter at the large end; $\frac{7}{10}$, or 0.700 inch at the small end; and $\frac{7}{2}$, or $3\frac{1}{2}$ inches long; hence, diameter at large end = No. of taper $\div 8$; diameter at small end = No. of taper $\div 10$; length of taper = No. of taper $\div 2$. The Jarno taper is used on various machine tools, especially profiling machines and die-sinking machines. It has also been used for the headstock and tailstock spindles of some lathes.

Table 4. Jarno Taper Shanks

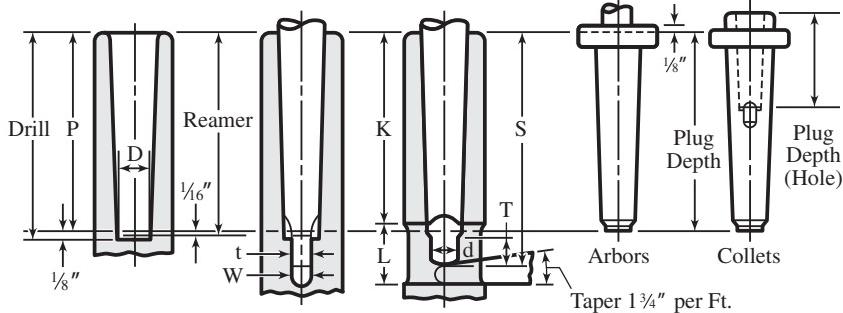


$$D = \frac{\text{No. of Taper}}{8} \quad C = \frac{\text{No. of Taper}}{10} \quad B = \frac{\text{No. of Taper}}{2}$$

| Number of Taper | Length A | Length B | Diameter C | Diameter D | Taper per foot |
|-----------------|-------------------|-----------------|------------|------------|----------------|
| 2 | 1 $\frac{1}{8}$ | 1 | 0.20 | 0.250 | 0.600 |
| 3 | 1 $\frac{5}{8}$ | 1 $\frac{1}{2}$ | 0.30 | 0.375 | 0.600 |
| 4 | 2 $\frac{3}{16}$ | 2 | 0.40 | 0.500 | 0.600 |
| 5 | 2 $\frac{11}{16}$ | 2 $\frac{1}{2}$ | 0.50 | 0.625 | 0.600 |
| 6 | 3 $\frac{3}{16}$ | 3 | 0.60 | 0.750 | 0.600 |
| 7 | 3 $\frac{11}{16}$ | 3 $\frac{1}{2}$ | 0.70 | 0.875 | 0.600 |
| 8 | 4 $\frac{3}{16}$ | 4 | 0.80 | 1.000 | 0.600 |
| 9 | 4 $\frac{11}{16}$ | 4 $\frac{1}{2}$ | 0.90 | 1.125 | 0.600 |
| 10 | 5 $\frac{1}{4}$ | 5 | 1.00 | 1.250 | 0.600 |
| 11 | 5 $\frac{3}{4}$ | 5 $\frac{1}{2}$ | 1.10 | 1.375 | 0.600 |
| 12 | 6 $\frac{1}{4}$ | 6 | 1.20 | 1.500 | 0.600 |
| 13 | 6 $\frac{3}{4}$ | 6 $\frac{1}{2}$ | 1.30 | 1.625 | 0.600 |
| 14 | 7 $\frac{1}{4}$ | 7 | 1.40 | 1.750 | 0.600 |
| 15 | 7 $\frac{3}{4}$ | 7 $\frac{1}{2}$ | 1.50 | 1.875 | 0.600 |
| 16 | 8 $\frac{5}{16}$ | 8 | 1.60 | 2.000 | 0.600 |
| 17 | 8 $\frac{13}{16}$ | 8 $\frac{1}{2}$ | 1.70 | 2.125 | 0.600 |
| 18 | 9 $\frac{5}{16}$ | 9 | 1.80 | 2.250 | 0.600 |
| 19 | 9 $\frac{13}{16}$ | 9 $\frac{1}{2}$ | 1.90 | 2.375 | 0.600 |
| 20 | 10 $\frac{5}{16}$ | 10 | 2.00 | 2.500 | 0.600 |

Brown & Sharpe Taper.—This standard taper is used for taper shanks on tools such as end mills and reamers, the taper being approximately $\frac{1}{2}$ inch per foot for all sizes except for taper No. 10, where the taper is 0.5161 inch per foot. Brown & Sharpe taper sockets are used for many arbors, collets, and machine tool spindles, especially milling machines and grinding machines. In many cases there are a number of different lengths of sockets corresponding to the same number of taper; all these tapers, however, are of the same diameter at the small end.

Table 5. Brown & Sharpe Taper Shanks



^a Special lengths of keyway are used instead of standard lengths in some places. Standard lengths need not be used when keyway is for driving only and not for admitting key to force out tool.

^b“B & S Standard” Plug Depths are not used in all cases.

^c Adopted by American Standards Association.

Table 6. Essential Dimensions of American National Standard Spindle Noses for Milling Machines ANSI B5.18-1972, R2004

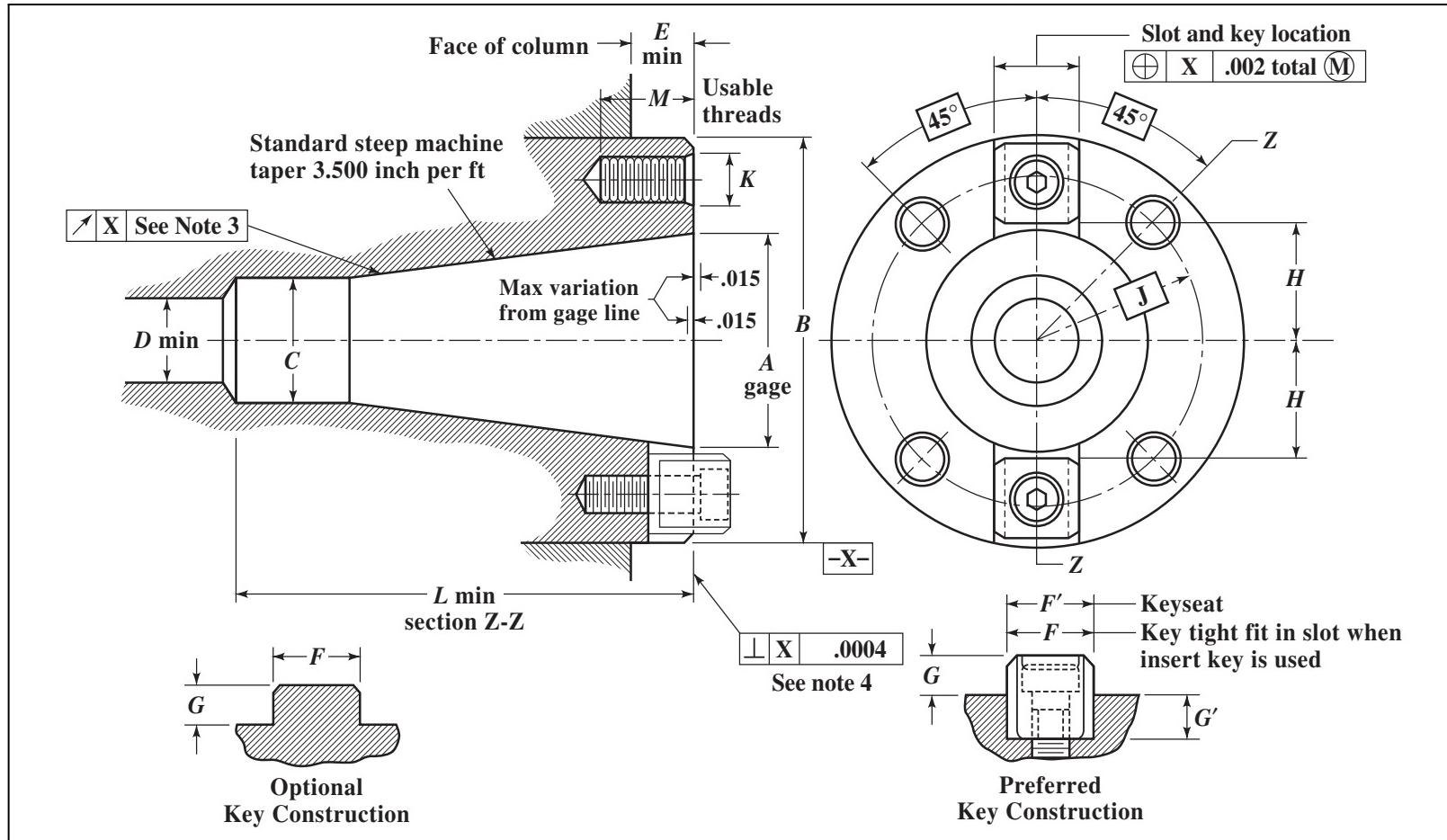


Table 6.(Continued) Essential Dimensions of American National Standard Spindle Noses for Milling Machines ANSI B5.18-1972, R2004

| Size No. | Gage Dia. of Taper A | Dia. of Spindle B | Pilot Dia. C | Clearance Hole for Draw-in Bolt Min. D | Minimum Dimension Spindle End to Column E | Width of Driving Key F | Width of Keyseat F' | Maximum Height of Driving Key G | Minimum Depth of Keyseat G' | Distance from Center to Driving Keys H | Radius of Bolt Hole Circle J | Size of Threads for Bolt Holes UNC-2B K | Full Depth of Arbor Hole in Spindle Min. L | Depth of Usable Thread for Bolt Hole M |
|----------|----------------------|-------------------|----------------|--|---|------------------------|---------------------|---------------------------------|-----------------------------|--|------------------------------|---|--|--|
| 30 | 1.250 | 2.7493 2.7488 | 0.692 0.685 | 0.66 | 0.50 | 0.6255 0.6252 | 0.624 0.625 | 0.31 | 0.31 | 0.660 0.654 | 1.0625 (Note 1) | 0.375-16 | 2.88 | 0.62 |
| 40 | 1.750 | 3.4993 3.4988 | 1.005 0.997 | 0.66 | 0.62 | 0.6255 0.6252 | 0.624 0.625 | 0.31 | 0.31 | 0.910 0.904 | 1.3125 (Note 1) | 0.500-13 | 3.88 | 0.81 |
| 45 | 2.250 | 3.9993 3.9988 | 1.286 1.278 | 0.78 | 0.62 | 0.7505 0.7502 | 0.749 0.750 | 0.38 | 0.38 | 1.160 1.154 | 1.500 (Note 1) | 0.500-13 | 4.75 | 0.81 |
| 50 | 2.750 | 5.0618 5.0613 | 1.568 1.559 | 1.06 | 0.75 | 1.0006 1.0002 | 0.999 1.000 | 0.50 | 0.50 | 1.410 1.404 | 2.000(Note 2) | 0.625-11 | 5.50 | 1.00 |
| 60 | 4.250 | 8.7180 8.7175 | 2.381 2.371 | 1.38 | 1.50 | 1.0006 1.0002 | 0.999 1.000 | 0.50 | 0.50 | 2.420 2.414 | 3.500 (Note 2) | 0.750-10 | 8.62 | 1.25 |

All dimensions are given in inches.

Tolerances:

Two-digit decimal dimensions ± 0.010 unless otherwise specified.

A—Taper: Tolerance on rate of taper to be 0.001 inch per foot applied only in direction which decreases rate of taper.

F'—Centrality of keyway with axis of taper 0.002 total at maximum material condition. (0.002 Total indicator variation)

F—Centrality of solid key with axis of taper 0.002 total at maximum material condition. (0.002 Total indicator variation)

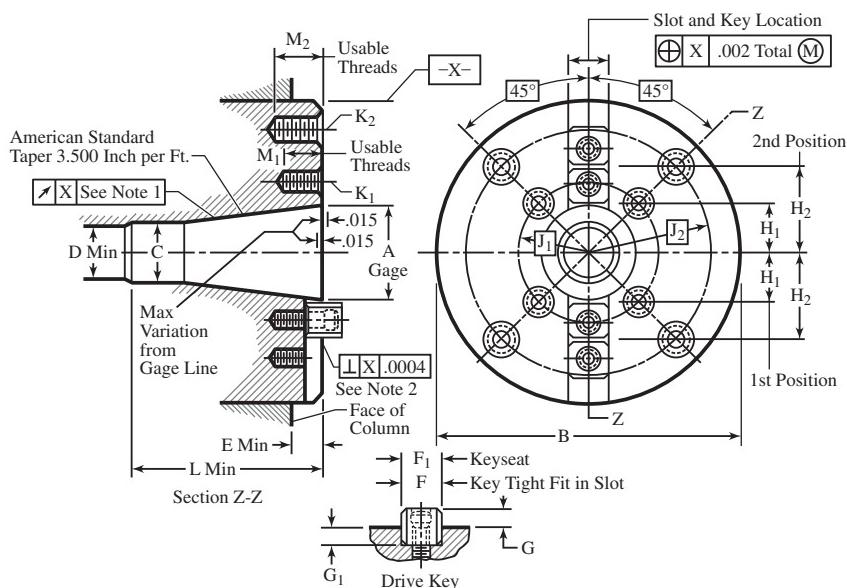
Note 1: Holes spaced as shown and located within 0.006 inch diameter of true position.

Note 2: Holes spaced as shown and located within 0.010 inch diameter of true position.

Note 3: Maximum turnout on test plug: 0.0004 at 1 inch projection from gage line. 0.0010 at 12 inch projection from gage line.

Note 4: Squareness of mounting face measured near mounting bolt hole circle.

Table 7. Essential Dimensions for American National Standard Spindle Nose with Large Flange ANSI B5.18-1972, R2004



| Size No. | Gage Diam. of Taper A | Dia. of Spindle Flange B | Pilot Dia. C | Clearance Hole for Draw-in Bolt Min. D | Min. Dim. Spindle End to Column E | Width of Driving Key F | Height of Driving Key Max. G | Depth of Keyseat Min. G1 | Distance from enter to Driving Keys First Position H1 |
|----------|--|--|----------------|--|-----------------------------------|--|---------------------------------------|--------------------------|---|
| 50A | 2.750 | 8.7180 8.7175 | 1.568 1.559 | 1.06 | 0.75 | 1.0006 1.0002 | 0.50 | 0.50 | 1.410 1.404 |
| Size No. | Distance from enter to Driving Key second Position | Radius of Bolt Hole Circles (See Note 3) | | Size of Threads for Bolt Holes UNC-2B | | Full Depth of Arbor Hole in Spindle Min. | Depth of Usable Thread for Bolt Holes | | Width of Keyseat |
| | | Inner | Outer | | | | | | |
| | H2 | J1 | J2 | K1 | K2 | L | M1 | M2 | F1 |
| 50A | 2.420 2.410 | 2.000 | 3.500 | 0.625-11 | 0.750-10 | 5.50 | 1.00 | 1.25 | 0.999 1.000 |

All dimensions are given in inches.

Tolerances: Two-digit decimal dimensions ± 0.010 unless otherwise specified.

A—Tolerance on rate of taper to be 0.001 inch per foot applied only in direction which decreases rate of taper.

F—Centrality of solid key with axis of taper 0.002 inch total at maximum material condition.
(0.002 inch Total indicator variation)

F₁—Centrality of keyseat with axis of taper 0.002 inch total at maximum material condition.
(0.002 inch Total indicator variation)

Note 1: Maximum runout on test plug:

0.0004 at 1 inch projection from gage line.

0.0010 at 12 inch projection from gage line.

Note 2: Squareness of mounting face measured near mounting bolt hole circle.

Note 3: Holes located as shown and within 0.010 inch diameter of true position.

**Table 8. Essential Dimensions of American National Standard Tool Shanks
for Milling Machines ANSI B5.18-1972, R2004**

| Size No. | Gage Dia. of Taper N | Tap Drill Size for Draw-in Thread O | Dia. of Neck P | Size of Thread for Draw-in Bolt UNC-2B M | Pilot Dia. R | Length of Pilot S | Minimum Length of Usable Thread T | Minimum Depth of Clearance Hole U |
|----------|----------------------|-------------------------------------|----------------|--|----------------|-------------------|-----------------------------------|-----------------------------------|
| 30 | 1.250 | 0.422 0.432 | 0.66 0.65 | 0.500-13 | 0.675 0.670 | 0.81 | 1.00 | 2.00 |
| 40 | 1.750 | 0.531 0.541 | 0.94 0.93 | 0.625-11 | 0.987 0.980 | 1.00 | 1.12 | 2.25 |
| 45 | 2.250 | 0.656 0.666 | 1.19 1.18 | 0.750-10 | 1.268 1.260 | 1.00 | 1.50 | 2.75 |
| 50 | 2.750 | 0.875 0.885 | 1.50 1.49 | 1.000-8 | 1.550 1.540 | 1.00 | 1.75 | 3.50 |
| 60 | 4.250 | 1.109 1.119 | 2.28 2.27 | 1.250-7 | 2.360 2.350 | 1.75 | 2.25 | 4.25 |

| Size. No. | Distance from Rear of Flange to End of Arbor V | Clearance of Flange from Gage Diameter W | Tool Shank Centerline to Driving Slot X | Width of Driving Slot Y | Distance from Gage Line to Bottom of C'bore Z | Depth of 60° Center K | Diameter of C'bore L |
|-----------|--|--|---|-------------------------|---|-----------------------|----------------------|
| 30 | 2.75 | 0.045 0.075 | 0.640 0.625 | 0.635 0.645 | 2.50 | 0.05 0.07 | 0.525 0.530 |
| 40 | 3.75 | 0.045 0.075 | 0.890 0.875 | 0.635 0.645 | 3.50 | 0.05 0.07 | 0.650 0.655 |
| 45 | 4.38 | 0.105 0.135 | 1.140 1.125 | 0.760 0.770 | 4.06 | 0.05 0.07 | 0.775 0.780 |
| 50 | 5.12 | 0.105 0.135 | 1.390 1.375 | 1.010 1.020 | 4.75 | 0.05 0.12 | 1.025 1.030 |
| 60 | 8.25 | 0.105 0.135 | 2.400 2.385 | 1.010 1.020 | 7.81 | 0.05 0.12 | 1.307 1.312 |

All dimensions are given in inches.

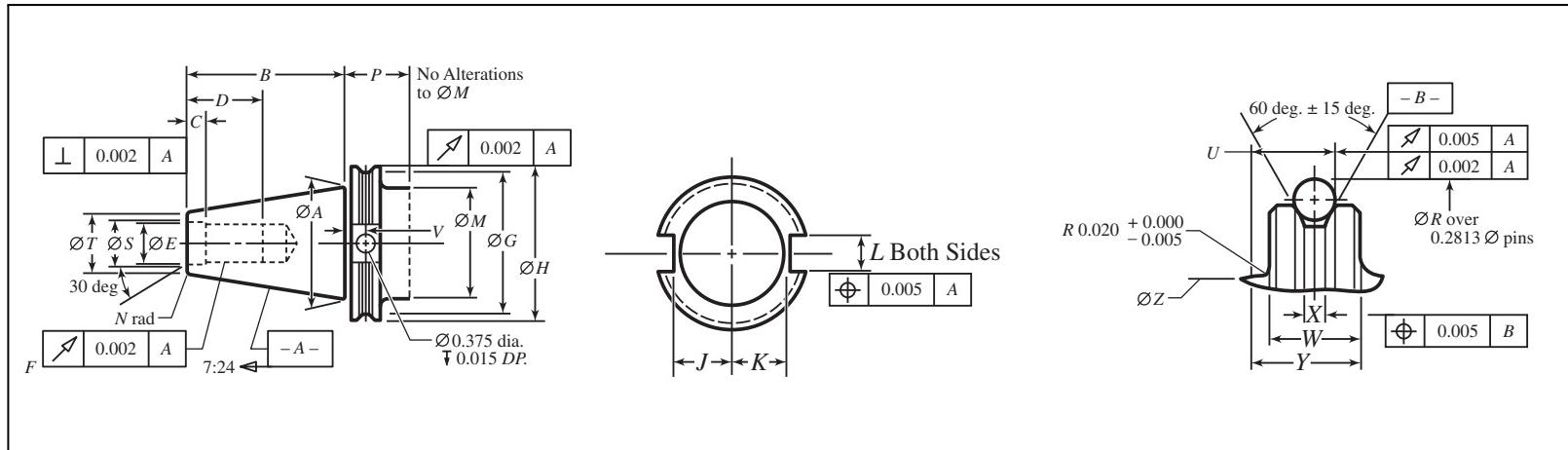
Tolerances: Two digit decimal dimensions ± 0.010 inch unless otherwise specified.

M—Permissible for Class 2B “No Go” gage to enter five threads before interference.

N—Taper tolerance on rate of taper to be 0.001 inch per foot applied only in direction which increases rate of taper.

Y—Centrality of drive slot with axis of taper shank 0.004 inch at maximum material condition.
(0.004 inch total indicator variation)

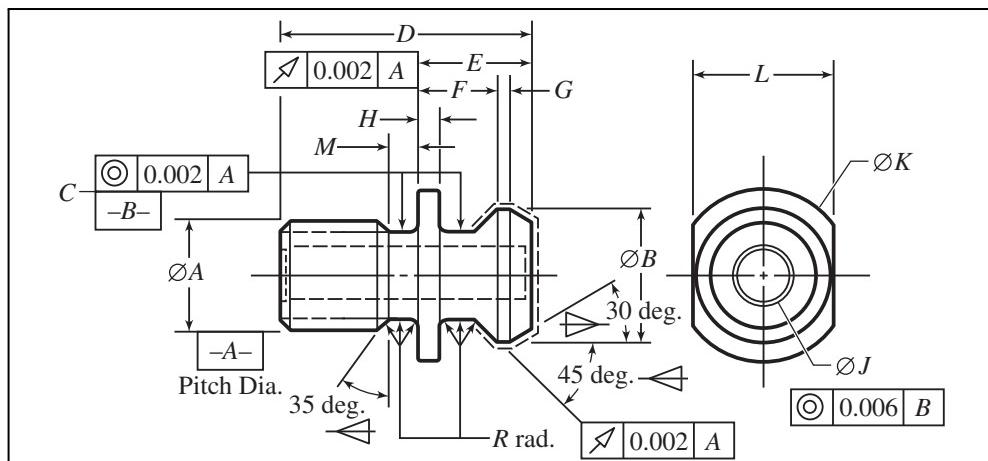
Table 9. Essential Dimensions of V-Flange Tool Shanks ANSI/ASME B5.50-1985, R2003



| Size No. | A | B | C | D | E | F | G | H | J | K | L | M | N | P | R | S | T | Z |
|----------|-----------|--------|--------|------|--------------------|----------|--------|--------|-------------------|-------------------|--------|--------|-------------------|-------|--------|--------|-----------|-------------------|
| | Gage Dia. | ±0.005 | ±0.010 | Min. | + 0.015 - 0.000 | UNC 2B | ±0.010 | ±0.002 | +0.000 - 0.015 | +0.000 - 0.015 | ±0.001 | ±0.005 | +0.000 - 0.015 | Min. | ±0.002 | ±0.010 | Min. Flat | +0.000 - 0.005 |
| 30 | 1.250 | 1.875 | 0.188 | 1.00 | 0.516 | 0.500–13 | 1.531 | 1.812 | 0.735 | 0.640 | 0.645 | 1.250 | 0.030 | 1.38 | 2.176 | 0.590 | 0.650 | 1.250 |
| 40 | 1.750 | 2.687 | 0.188 | 1.12 | 0.641 | 0.625–11 | 2.219 | 2.500 | 0.985 | 0.890 | 0.645 | 1.750 | 0.060 | 1.38 | 2.863 | 0.720 | 0.860 | 1.750 |
| 45 | 2.250 | 3.250 | 0.188 | 1.50 | 0.766 | 0.750–10 | 2.969 | 3.250 | 1.235 | 1.140 | 0.770 | 2.250 | 0.090 | 1.38 | 3.613 | 0.850 | 1.090 | 2.250 |
| 50 | 2.750 | 4.000 | 0.250 | 1.75 | 1.031 | 1.000–8 | 3.594 | 3.875 | 1.485 | 1.390 | 1.020 | 2.750 | 0.090 | 1.38 | 4.238 | 1.125 | 1.380 | 2.750 |
| 60 | 4.250 | 6.375 | 0.312 | 2.25 | 1.281 | 1.250–7 | 5.219 | 5.500 | 2.235 | 2.140 | 1.020 | 4.250 | 0.120 0.200 | 1.500 | 5.683 | 1.375 | 2.04 | 4.250 |

Notes: Taper tolerance to be 0.001 in. in 12 in. applied in direction that increases rate of taper. Geometric dimensions symbols are to ANSI Y14.5M-1994. Dimensions are in inches. Deburr all sharp edges. Unspecified fillets and radii to be $0.03 \pm 0.010R$, or $0.03 \pm 0.010 \times 45$ degrees. Data for size 60 are not part of Standard. For all sizes, the values for dimensions U (tol. ± 0.005) are 0.579; for V (tol. ± 0.010), 0.440; for W (tol. ± 0.002), 0.625; for X (tol. ± 0.005), 0.151; and for Y (tol. ± 0.002), 0.750.

Table 10. Essential Dimensions of V-Flange Tool Shank Retention Knobs
ANSI/ASME B5.50-1985



| Size/ Totals | A | B | C | D | E | F |
|-----------------|----------|-------------|-------------|-------------|-------------|-------------|
| | UNC 2A | ± 0.005 | ± 0.005 | ± 0.040 | ± 0.005 | ± 0.005 |
| 30 | 0.500-13 | 0.520 | 0.385 | 1.10 | 0.460 | 0.320 |
| 40 | 0.625-11 | 0.740 | 0.490 | 1.50 | 0.640 | 0.440 |
| 45 | 0.750-10 | 0.940 | 0.605 | 1.80 | 0.820 | 0.580 |
| 50 | 1.000-8 | 1.140 | 0.820 | 2.30 | 1.000 | 0.700 |
| 60 | 1.250-7 | 1.460 | 1.045 | 3.20 | 1.500 | 1.080 |

| Size / Totals | G | H | J | K | L | M | R |
|------------------|-------------|-------------|-------------|------------------|----------------------|-------------|----------------------|
| | ± 0.010 | ± 0.010 | ± 0.010 | | $+0.000$ -0.010 | ± 0.040 | $+0.010$ -0.005 |
| 30 | 0.04 | 0.10 | 0.187 | 0.65 0.64 | 0.53 | 0.19 | 0.094 |
| 40 | 0.06 | 0.12 | 0.281 | 0.94 0.92 | 0.75 | 0.22 | 0.094 |
| 45 | 0.08 | 0.16 | 0.375 | 1.20 1.18 | 1.00 | 0.22 | 0.094 |
| 50 | 0.10 | 0.20 | 0.468 | 1.44 1.42 | 1.25 | 0.25 | 0.125 |
| 60 | 0.14 | 0.30 | 0.500 | 2.14 2.06 | 1.50 | 0.31 | 0.125 |

Notes: Dimensions are in inches. Material: low-carbon steel. Heat treatment: carburize and harden to 0.016 to 0.028 in. effective case depth. Hardness of noted surfaces to be Rockwell 56-60; core hardness Rockwell C35-45. Hole J shall not be carburized. Surfaces C and R to be free from tool marks. Deburr all sharp edges. Geometric dimension symbols are to ANSI Y14.5M-1994. Data for size 60 are not part of Standard.

THREADS

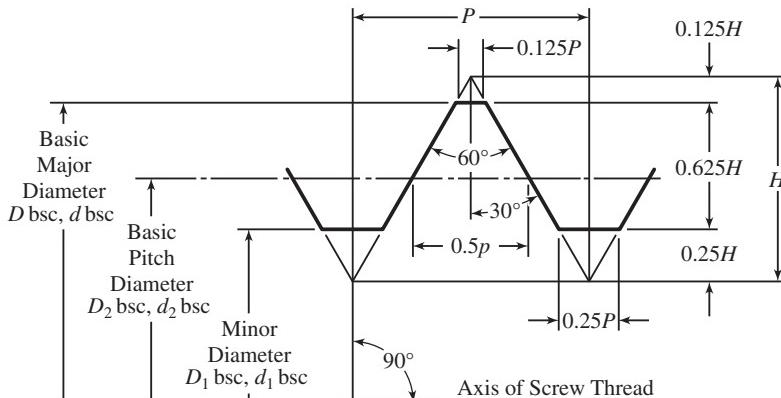


Fig. 1. Basic Profile of UN and UNF Screw Threads

Thread Classes.— Thread classes are distinguished from each other by the amounts of tolerance and allowance. Classes identified by a numeral followed by the letters A and B are derived from certain Unified formulas (not shown here) in which the pitch diameter tolerances are based on increments of the basic major (nominal) diameter, the pitch, and the length of engagement. These formulas and the class identification or symbols apply to all of the Unified threads.

Classes 1A, 2A, and 3A apply to external threads only, and Classes 1B, 2B, and 3B apply to internal threads only. The disposition of the tolerances, allowances, and crest clearances for the various classes is illustrated on pages 56 and 57.

Classes 2A and 2B: Classes 2A and 2B are the most commonly used for general applications, including production of bolts, screws, nuts, and similar fasteners.

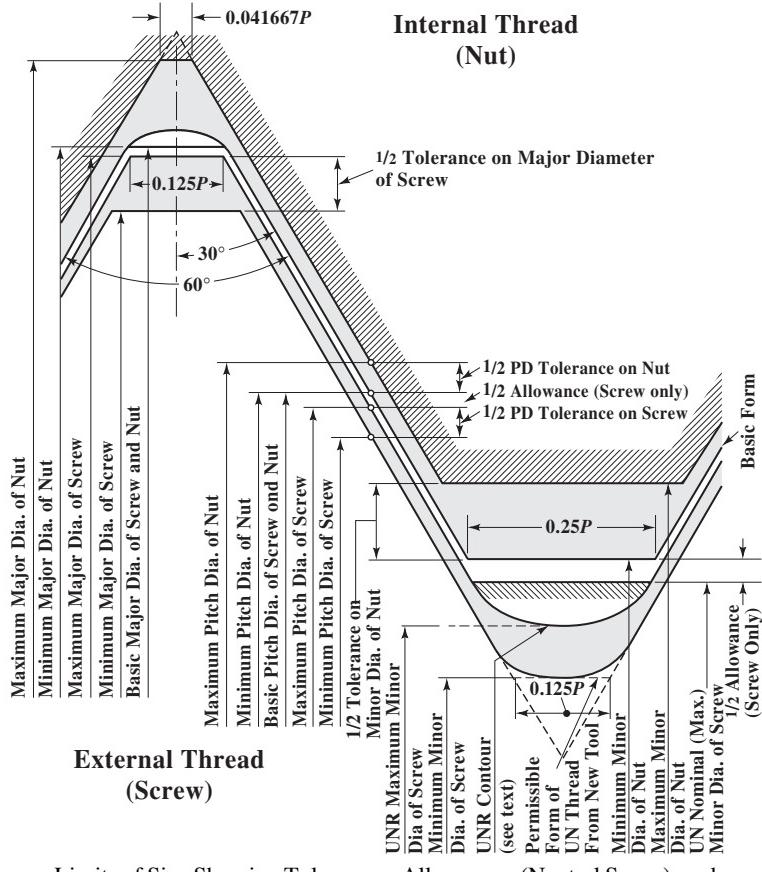
The maximum diameters of Class 2A (external) uncoated threads are less than basic by the amount of the allowance. The allowance minimizes galling and seizing in high-cycle wrench assembly, or it can be used to accommodate plated finishes or other coating. However, for threads with additive finish, the maximum diameters of Class 2A may be exceeded by the amount of the allowance, for example, the 2A maximum diameters apply to an unplated part or to a part before plating whereas the basic diameters (the 2A maximum diameter plus allowance) apply to a part after plating. The minimum diameters of Class 2B (internal) threads, whether or not plated or coated, are basic, affording no allowance or clearance in assembly at maximum metal limits.

Class 2AG: Certain applications require an allowance for rapid assembly to permit application of the proper lubricant or for residual growth due to high-temperature expansion. In these applications, when the thread is coated and the 2A allowance is not permitted to be consumed by such coating, the thread class symbol is qualified by G following the class symbol.

Classes 3A and 3B: Classes 3A and 3B may be used if closer tolerances are desired than those provided by Classes 2A and 2B. The maximum diameters of Class 3A (external) threads and the minimum diameters of Class 3B (internal) threads, whether or not plated or coated, are basic, affording no allowance or clearance for assembly of maximum metal components.

Classes 1A and 1B: Classes 1A and 1B threads replaced American National Class 1. These classes are intended for ordnance and other special uses. They are used on threaded components where quick and easy assembly is necessary and where a liberal allowance is required to permit ready assembly, even with slightly bruised or dirty threads.

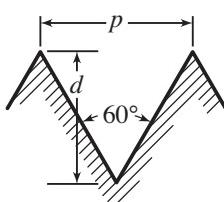
Maximum diameters of Class 1A (external) threads are less than basic by the amount of the same allowance as applied to Class 2A. For the intended applications in American practice the allowance is not available for plating or coating. Where the thread is plated or coated, special provisions are necessary. The minimum diameters of Class 1B (internal) threads, whether or not plated or coated, are basic, affording no allowance or clearance for assembly with maximum metal external thread components having maximum diameters which are basic.



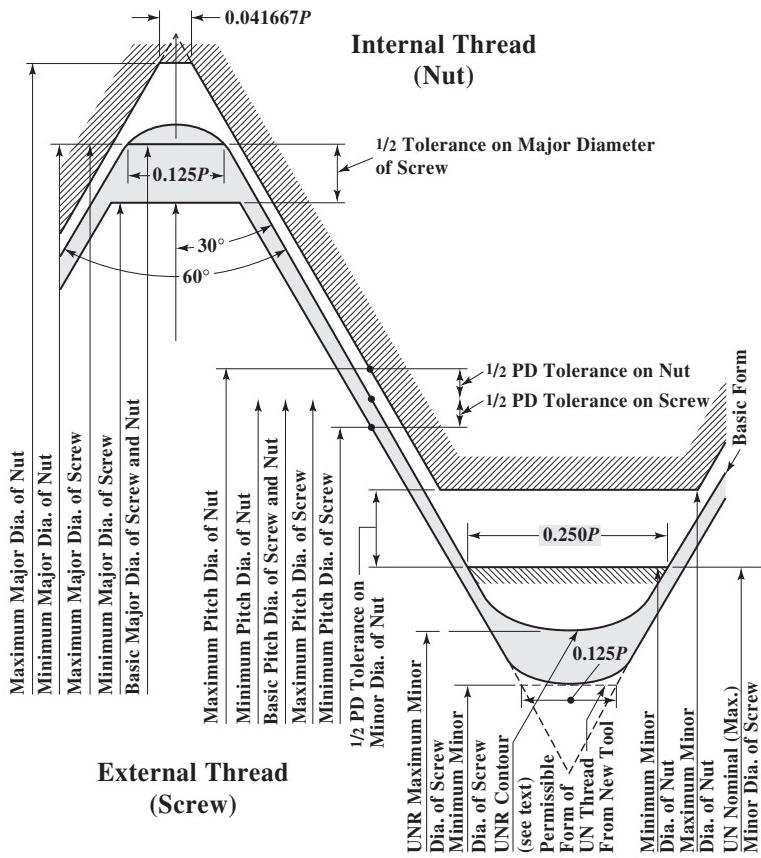
Limits of Size Showing Tolerances, Allowances (Neutral Space), and Crest Clearances for Unified Classes 1A, 2A, 1B, and 2B

Sharp V-thread.—The sides of the thread form an angle of 60 degrees with each other. The top and bottom of the thread are, theoretically, sharp, but in practice it is necessary to make the thread with a slight flat. There is no standard adopted for this flat, but it is usually made about one-twenty-fifth of the pitch. If p = pitch of thread, and d = depth of thread, then:

$$d = p \times \cos 30 \text{ deg.} = p \times 0.866 = \frac{0.86603}{\text{no. of threads per inch}}$$



Some modified V-threads, for locomotive boiler taps particularly, have a depth of $0.8 \times$ pitch.



Limits of Size Showing Tolerances and Crest Clearances for Unified Classes 3A and 3B and American National Classes 2 and 3

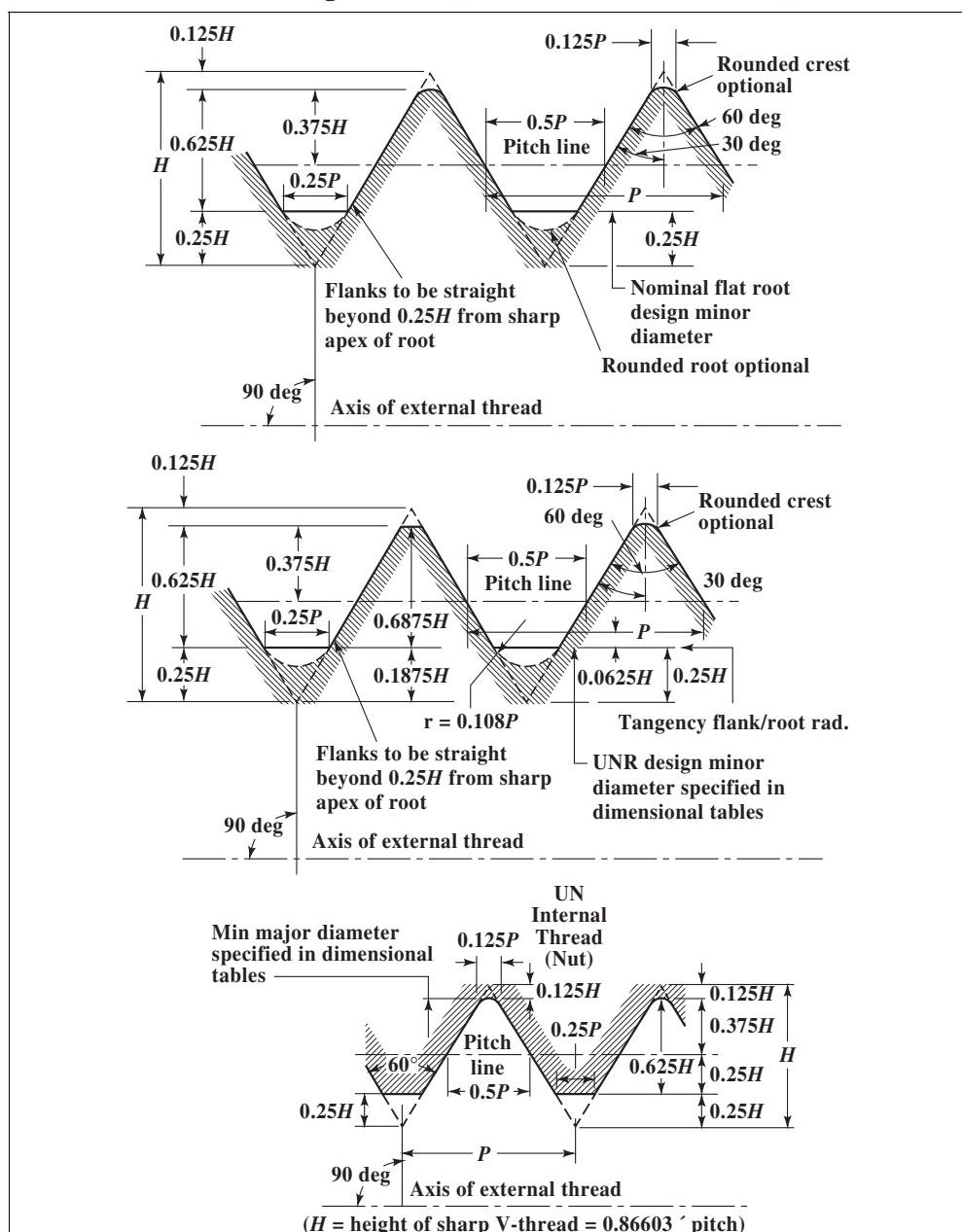
UN External Screw Threads: A flat root contour is specified, but it is necessary to provide for some threading tool crest wear, hence a rounded root contour cleared beyond the $0.25P$ flat width of the Basic Profile is optional.

UNR External Screw Threads: To reduce the rate of threading tool crest wear and to improve fatigue strength of a flat root thread, the Design Profile of the UNR thread has a smooth, continuous, non-reversing contour with a radius of curvature not less than $0.108P$ at any point and blends tangentially into the flanks and any straight segment. At the maximum material condition, the point of tangency is specified to be at a distance not less than $0.625H$ (where H is the height of a sharp V-thread) below the basic major diameter.

UN and UNR External Screw Threads: The design profiles of both UN and UNR external screw threads have flat crests. However, in practice, product threads are produced with partially or completely rounded crests. A rounded crest tangent at $0.125P$ flat is shown as an option on page .

UN Internal Screw Thread: In practice it is necessary to provide for some threading tool crest wear, therefore the root of the design profile is rounded and cleared beyond the $0.125P$ flat width of the basic profile. There is no internal UNR screw thread.

Table 1. American National Standard Unified Internal and External Screw Thread Design Profiles (Maximum Material Condition)



Fine-Thread Series.— This series, UNF/UNRF, is suitable for the production of bolts, screws, and nuts and for other applications where the Coarse series is not applicable. External threads of this series have greater tensile stress area than comparable sizes of the Coarse series. The Fine series is suitable when the resistance to stripping of both external and mating internal threads equals or exceeds the tensile load carrying capacity of the externally threaded member. It is also used where the length of engagement is short, where a smaller lead angle is desired, where the wall thickness demands a fine pitch, or where finer adjustment is needed.

Table 2. Standard Series and Selected Combinations — Unified Screw Threads

| Nominal Size, Threads per Inch, and Series Designation ^a | External ^b | | | | | | | | Internal ^b | | | | | | | |
|--|-----------------------|-----------|------------------|--------|------------------|------------------|--------|--|-----------------------|----------------|--------|----------------|--------|--------------------------|--|--|
| | Class | Allowance | Major Diameter | | | Pitch Diameter | | UNR Minor Dia. ^c Max (Ref.) | Class | Minor Diameter | | Pitch Diameter | | Major Diameter Min | | |
| | | | Max ^d | Min | Min ^e | Max ^d | Min | | | Min | Max | Min | Max | | | |
| 0-80 UNF | 2A | 0.0005 | 0.0595 | 0.0563 | — | 0.0514 | 0.0496 | 0.0446 | 2B | 0.0465 | 0.0514 | 0.0519 | 0.0542 | 0.0600 | | |
| | 3A | 0.0000 | 0.0600 | 0.0568 | — | 0.0519 | 0.0506 | 0.0451 | 3B | 0.0465 | 0.0514 | 0.0519 | 0.0536 | 0.0600 | | |
| 1-64 UNC | 2A | 0.0006 | 0.0724 | 0.0686 | — | 0.0623 | 0.0603 | 0.0538 | 2B | 0.0561 | 0.0623 | 0.0629 | 0.0655 | 0.0730 | | |
| | 3A | 0.0000 | 0.0730 | 0.0692 | — | 0.0629 | 0.0614 | 0.0544 | 3B | 0.0561 | 0.0623 | 0.0629 | 0.0648 | 0.0730 | | |
| 1-72 UNF | 2A | 0.0006 | 0.0724 | 0.0689 | — | 0.0634 | 0.0615 | 0.0559 | 2B | 0.0580 | 0.0635 | 0.0640 | 0.0665 | 0.0730 | | |
| | 3A | 0.0000 | 0.0730 | 0.0695 | — | 0.0640 | 0.0626 | 0.0565 | 3B | 0.0580 | 0.0635 | 0.0640 | 0.0659 | 0.0730 | | |
| 2-56 UNC | 2A | 0.0006 | 0.0854 | 0.0813 | — | 0.0738 | 0.0717 | 0.0642 | 2B | 0.0667 | 0.0737 | 0.0744 | 0.0772 | 0.0860 | | |
| | 3A | 0.0000 | 0.0860 | 0.0819 | — | 0.0744 | 0.0728 | 0.0648 | 3B | 0.0667 | 0.0737 | 0.0744 | 0.0765 | 0.0860 | | |
| 2-64 UNF | 2A | 0.0006 | 0.0854 | 0.0816 | — | 0.0753 | 0.0733 | 0.0668 | 2B | 0.0691 | 0.0753 | 0.0759 | 0.0786 | 0.0860 | | |
| | 3A | 0.0000 | 0.0860 | 0.0822 | — | 0.0759 | 0.0744 | 0.0674 | 3B | 0.0691 | 0.0753 | 0.0759 | 0.0779 | 0.0860 | | |
| 3-48 UNC | 2A | 0.0007 | 0.0983 | 0.0938 | — | 0.0848 | 0.0825 | 0.0734 | 2B | 0.0764 | 0.0845 | 0.0855 | 0.0885 | 0.0990 | | |
| | 3A | 0.0000 | 0.0990 | 0.0945 | — | 0.0855 | 0.0838 | 0.0741 | 3B | 0.0764 | 0.0845 | 0.0855 | 0.0877 | 0.0990 | | |
| 3-56 UNF | 2A | 0.0007 | 0.0983 | 0.0942 | — | 0.0867 | 0.0845 | 0.0771 | 2B | 0.0797 | 0.0865 | 0.0874 | 0.0902 | 0.0990 | | |
| | 3A | 0.0000 | 0.0990 | 0.0949 | — | 0.0874 | 0.0858 | 0.0778 | 3B | 0.0797 | 0.0865 | 0.0874 | 0.0895 | 0.0990 | | |
| 4-40 UNC | 2A | 0.0008 | 0.1112 | 0.1061 | — | 0.0950 | 0.0925 | 0.0814 | 2B | 0.0849 | 0.0939 | 0.0958 | 0.0991 | 0.1120 | | |
| | 3A | 0.0000 | 0.1120 | 0.1069 | — | 0.0958 | 0.0939 | 0.0822 | 3B | 0.0849 | 0.0939 | 0.0958 | 0.0982 | 0.1120 | | |
| 4-48 UNF | 2A | 0.0007 | 0.1113 | 0.1068 | — | 0.0978 | 0.0954 | 0.0864 | 2B | 0.0894 | 0.0968 | 0.0985 | 0.1016 | 0.1120 | | |
| | 3A | 0.0000 | 0.1120 | 0.1075 | — | 0.0985 | 0.0967 | 0.0871 | 3B | 0.0894 | 0.0968 | 0.0985 | 0.1008 | 0.1120 | | |
| 5-40 UNC | 2A | 0.0008 | 0.1242 | 0.1191 | — | 0.1080 | 0.1054 | 0.0944 | 2B | 0.0979 | 0.1062 | 0.1088 | 0.1121 | 0.1250 | | |
| | 3A | 0.0000 | 0.1250 | 0.1199 | — | 0.1088 | 0.1069 | 0.0952 | 3B | 0.0979 | 0.1062 | 0.1088 | 0.1113 | 0.1250 | | |
| 5-44 UNF | 2A | 0.0007 | 0.1243 | 0.1195 | — | 0.1095 | 0.1070 | 0.0972 | 2B | 0.1004 | 0.1079 | 0.1102 | 0.1134 | 0.1250 | | |
| | 3A | 0.0000 | 0.1250 | 0.1202 | — | 0.1102 | 0.1083 | 0.0979 | 3B | 0.1004 | 0.1079 | 0.1102 | 0.1126 | 0.1250 | | |
| 6-32 UNC | 2A | 0.0008 | 0.1372 | 0.1312 | — | 0.1169 | 0.1141 | 0.1000 | 2B | 0.104 | 0.114 | 0.1177 | 0.1214 | 0.1380 | | |
| | 3A | 0.0000 | 0.1380 | 0.1320 | — | 0.1177 | 0.1156 | 0.1008 | 3B | 0.1040 | 0.1140 | 0.1177 | 0.1204 | 0.1380 | | |
| 6-40 UNF | 2A | 0.0008 | 0.1372 | 0.1321 | — | 0.1210 | 0.1184 | 0.1074 | 2B | 0.111 | 0.119 | 0.1218 | 0.1252 | 0.1380 | | |
| | 3A | 0.0000 | 0.1380 | 0.1329 | — | 0.1218 | 0.1198 | 0.1082 | 3B | 0.1110 | 0.1186 | 0.1218 | 0.1243 | 0.1380 | | |
| 8-32 UNC | 2A | 0.0009 | 0.1631 | 0.1571 | — | 0.1428 | 0.1399 | 0.1259 | 2B | 0.130 | 0.139 | 0.1437 | 0.1475 | 0.1640 | | |
| | 3A | 0.0000 | 0.1640 | 0.1580 | — | 0.1437 | 0.1415 | 0.1268 | 3B | 0.1300 | 0.1389 | 0.1437 | 0.1465 | 0.1640 | | |
| 8-36 UNF | 2A | 0.0008 | 0.1632 | 0.1577 | — | 0.1452 | 0.1424 | 0.1301 | 2B | 0.134 | 0.142 | 0.1460 | 0.1496 | 0.1640 | | |
| | 3A | 0.0000 | 0.1640 | 0.1585 | — | 0.1460 | 0.1439 | 0.1309 | 3B | 0.1340 | 0.1416 | 0.1460 | 0.1487 | 0.1640 | | |
| 10-24 UNC | 2A | 0.0010 | 0.1890 | 0.1818 | — | 0.1619 | 0.1586 | 0.1394 | 2B | 0.145 | 0.156 | 0.1629 | 0.1672 | 0.1900 | | |
| | 3A | 0.0000 | 0.1900 | 0.1828 | — | 0.1629 | 0.1604 | 0.1404 | 3B | 0.1450 | 0.1555 | 0.1629 | 0.1661 | 0.1900 | | |
| 10-32 UNF | 2A | 0.0009 | 0.1891 | 0.1831 | — | 0.1688 | 0.1658 | 0.1519 | 2B | 0.156 | 0.164 | 0.1697 | 0.1736 | 0.1900 | | |
| | 3A | 0.0000 | 0.1900 | 0.1840 | — | 0.1697 | 0.1674 | 0.1528 | 3B | 0.1560 | 0.1641 | 0.1697 | 0.1726 | 0.1900 | | |
| 12-24 UNC | 2A | 0.0010 | 0.2150 | 0.2078 | — | 0.1879 | 0.1845 | 0.1654 | 2B | 0.171 | 0.181 | 0.1889 | 0.1933 | 0.2160 | | |
| | 3A | 0.0000 | 0.2160 | 0.2088 | — | 0.1889 | 0.1863 | 0.1664 | 3B | 0.1710 | 0.1807 | 0.1889 | 0.1922 | 0.2160 | | |

Table 2. (Continued) Standard Series and Selected Combinations — Unified Screw Threads

| Nominal Size, Threads per Inch, and Series Designation ^a | External ^b | | | | | | | | Internal ^b | | | | | | | |
|--|-----------------------|-----------|------------------|--------|------------------|------------------|--------|--|-----------------------|----------------|--------|----------------|--------|--------------------------|--|--|
| | Class | Allowance | Major Diameter | | | Pitch Diameter | | UNR Minor Dia. ^c Max (Ref.) | Class | Minor Diameter | | Pitch Diameter | | Major Diameter Min | | |
| | | | Max ^d | Min | Min ^e | Max ^d | Min | | | Min | Max | Min | Max | | | |
| 12-28 UNF | 2A | 0.0010 | 0.2150 | 0.2085 | — | 0.1918 | 0.1886 | 0.1724 | 2B | 0.177 | 0.186 | 0.1928 | 0.1970 | 0.2160 | | |
| | 3A | 0.0000 | 0.2160 | 0.2095 | — | 0.1928 | 0.1904 | 0.1734 | 3B | 0.1770 | 0.1857 | 0.1928 | 0.1959 | 0.2160 | | |
| 1/4-20 UNC | 1A | 0.0011 | 0.2489 | 0.2367 | — | 0.2164 | 0.2108 | 0.1894 | 1B | 0.196 | 0.207 | 0.2175 | 0.2248 | 0.2500 | | |
| | 2A | 0.0011 | 0.2489 | 0.2408 | 0.2367 | 0.2164 | 0.2127 | 0.1894 | 2B | 0.196 | 0.207 | 0.2175 | 0.2224 | 0.2500 | | |
| 1/4-28 UNF | 3A | 0.0000 | 0.2500 | 0.2419 | — | 0.2175 | 0.2147 | 0.1905 | 3B | 0.1960 | 0.2067 | 0.2175 | 0.2211 | 0.2500 | | |
| | 1A | 0.0010 | 0.2490 | 0.2392 | — | 0.2258 | 0.2208 | 0.2064 | 1B | 0.211 | 0.220 | 0.2268 | 0.2333 | 0.2500 | | |
| 1/4-28 UNF | 2A | 0.0010 | 0.2490 | 0.2425 | — | 0.2258 | 0.2225 | 0.2064 | 2B | 0.211 | 0.220 | 0.2268 | 0.2311 | 0.2500 | | |
| | 3A | 0.0000 | 0.2500 | 0.2435 | — | 0.2268 | 0.2243 | 0.2074 | 3B | 0.2110 | 0.2190 | 0.2268 | 0.2300 | 0.2500 | | |
| 5/16-18 UNC | 1A | 0.0012 | 0.3113 | 0.2982 | — | 0.2752 | 0.2691 | 0.2452 | 1B | 0.252 | 0.265 | 0.2764 | 0.2843 | 0.3125 | | |
| | 2A | 0.0012 | 0.3113 | 0.3026 | 0.2982 | 0.2752 | 0.2712 | 0.2452 | 2B | 0.252 | 0.265 | 0.2764 | 0.2817 | 0.3125 | | |
| 5/16-24 UNF | 3A | 0.0000 | 0.3125 | 0.3038 | — | 0.2764 | 0.2734 | 0.2464 | 3B | 0.2520 | 0.2630 | 0.2764 | 0.2803 | 0.3125 | | |
| | 1A | 0.0011 | 0.3114 | 0.3006 | — | 0.2843 | 0.2788 | 0.2618 | 1B | 0.267 | 0.277 | 0.2854 | 0.2925 | 0.3125 | | |
| 3/8-16 UNC | 2A | 0.0011 | 0.3114 | 0.3042 | — | 0.2843 | 0.2806 | 0.2618 | 2B | 0.267 | 0.277 | 0.2854 | 0.2902 | 0.3125 | | |
| | 3A | 0.0000 | 0.3125 | 0.3053 | — | 0.2854 | 0.2827 | 0.2629 | 3B | 0.2670 | 0.2754 | 0.2854 | 0.2890 | 0.3125 | | |
| 3/8-24 UNF | 1A | 0.0013 | 0.3737 | 0.3595 | — | 0.3331 | 0.3266 | 0.2992 | 1B | 0.307 | 0.321 | 0.3344 | 0.3429 | 0.3750 | | |
| | 2A | 0.0013 | 0.3737 | 0.3643 | 0.3595 | 0.3331 | 0.3287 | 0.2992 | 2B | 0.307 | 0.321 | 0.3344 | 0.3401 | 0.3750 | | |
| 3/8-24 UNF | 3A | 0.0000 | 0.3750 | 0.3656 | — | 0.3344 | 0.3311 | 0.3005 | 3B | 0.3070 | 0.3182 | 0.3344 | 0.3387 | 0.3750 | | |
| | 1A | 0.0011 | 0.3739 | 0.3631 | — | 0.3468 | 0.3411 | 0.3243 | 1B | 0.330 | 0.340 | 0.3479 | 0.3553 | 0.3750 | | |
| 5/16-14 UNC | 2A | 0.0011 | 0.3739 | 0.3667 | — | 0.3468 | 0.3430 | 0.3243 | 2B | 0.330 | 0.340 | 0.3479 | 0.3528 | 0.3750 | | |
| | 3A | 0.0000 | 0.3750 | 0.3678 | — | 0.3479 | 0.3450 | 0.3254 | 3B | 0.3300 | 0.3372 | 0.3479 | 0.3516 | 0.3750 | | |
| 5/16-14 UNC | 1A | 0.0014 | 0.4361 | 0.4206 | — | 0.3897 | 0.3826 | 0.3511 | 1B | 0.360 | 0.376 | 0.3911 | 0.4003 | 0.4375 | | |
| | 2A | 0.0014 | 0.4361 | 0.4258 | 0.4206 | 0.3897 | 0.3850 | 0.3511 | 2B | 0.360 | 0.376 | 0.3911 | 0.3972 | 0.4375 | | |
| 1/2-13 UNC | 3A | 0.0000 | 0.4375 | 0.4272 | — | 0.3911 | 0.3876 | 0.3525 | 3B | 0.3600 | 0.3717 | 0.3911 | 0.3957 | 0.4375 | | |
| | 1A | 0.0015 | 0.4985 | 0.4822 | — | 0.4485 | 0.4411 | 0.4069 | 1B | 0.417 | 0.434 | 0.4500 | 0.4597 | 0.5000 | | |
| 1/2-20 UNF | 2A | 0.0015 | 0.4985 | 0.4876 | 0.4822 | 0.4485 | 0.4435 | 0.4069 | 2B | 0.417 | 0.434 | 0.4500 | 0.4565 | 0.5000 | | |
| | 3A | 0.0000 | 0.5000 | 0.4891 | — | 0.4500 | 0.4463 | 0.4084 | 3B | 0.4170 | 0.4284 | 0.4500 | 0.4548 | 0.5000 | | |
| 1/2-20 UNF | 1A | 0.0013 | 0.4987 | 0.4865 | — | 0.4662 | 0.4598 | 0.4392 | 1B | 0.446 | 0.457 | 0.4675 | 0.4759 | 0.5000 | | |
| | 2A | 0.0013 | 0.4987 | 0.4906 | — | 0.4662 | 0.4619 | 0.4392 | 2B | 0.446 | 0.457 | 0.4675 | 0.4731 | 0.5000 | | |
| 5/16-12 UNC | 3A | 0.0000 | 0.5000 | 0.4919 | — | 0.4675 | 0.4643 | 0.4405 | 3B | 0.4460 | 0.4537 | 0.4675 | 0.4717 | 0.5000 | | |
| | 1A | 0.0016 | 0.5609 | 0.5437 | — | 0.5068 | 0.4990 | 0.4617 | 1B | 0.472 | 0.490 | 0.5084 | 0.5186 | 0.5625 | | |
| 5/16-18 UNF | 2A | 0.0016 | 0.5609 | 0.5495 | 0.5437 | 0.5068 | 0.5016 | 0.4617 | 2B | 0.472 | 0.490 | 0.5084 | 0.5152 | 0.5625 | | |
| | 3A | 0.0000 | 0.5625 | 0.5511 | — | 0.5084 | 0.5045 | 0.4633 | 3B | 0.4720 | 0.4843 | 0.5084 | 0.5135 | 0.5625 | | |
| 5/16-18 UNF | 1A | 0.0014 | 0.5611 | 0.5480 | — | 0.5250 | 0.5182 | 0.4950 | 1B | 0.502 | 0.515 | 0.5264 | 0.5353 | 0.5625 | | |
| | 2A | 0.0014 | 0.5611 | 0.5524 | — | 0.5250 | 0.5205 | 0.4950 | 2B | 0.502 | 0.515 | 0.5264 | 0.5323 | 0.5625 | | |

Table 2.(Continued) Standard Series and Selected Combinations — Unified Screw Threads

| Nominal Size, Threads per Inch, and Series Designation ^a | External ^b | | | | | | | | | Internal ^b | | | | | | | | |
|--|-----------------------|-----------|------------------|--------|------------------|------------------|--------|--|-------|-----------------------|--------|----------------|--------|--------------------------|--|--|--|--|
| | Class | Allowance | Major Diameter | | | Pitch Diameter | | UNR Minor Dia. ^c Max (Ref.) | Class | Minor Diameter | | Pitch Diameter | | Major Diameter Min | | | | |
| | | | Max ^d | Min | Min ^e | Max ^d | Min | | | Min | Max | Min | Max | | | | | |
| $\frac{5}{8}$ -11 UNC | 3A | 0.0000 | 0.5625 | 0.5538 | — | 0.5264 | 0.5230 | 0.4964 | 3B | 0.5020 | 0.5106 | 0.5264 | 0.5308 | 0.5625 | | | | |
| | 1A | 0.0016 | 0.6234 | 0.6052 | — | 0.5644 | 0.5561 | 0.5152 | 1B | 0.527 | 0.546 | 0.5660 | 0.5767 | 0.6250 | | | | |
| | 2A | 0.0016 | 0.6234 | 0.6113 | 0.6052 | 0.5644 | 0.5589 | 0.5152 | 2B | 0.527 | 0.546 | 0.5660 | 0.5732 | 0.6250 | | | | |
| $\frac{5}{8}$ -18 UNF | 3A | 0.0000 | 0.6250 | 0.6129 | — | 0.5660 | 0.5619 | 0.5168 | 3B | 0.5270 | 0.5391 | 0.5660 | 0.5714 | 0.6250 | | | | |
| | 1A | 0.0014 | 0.6236 | 0.6105 | — | 0.5875 | 0.5805 | 0.5575 | 1B | 0.565 | 0.578 | 0.5889 | 0.5980 | 0.6250 | | | | |
| | 2A | 0.0014 | 0.6236 | 0.6149 | — | 0.5875 | 0.5828 | 0.5575 | 2B | 0.565 | 0.578 | 0.5889 | 0.5949 | 0.6250 | | | | |
| $\frac{3}{4}$ -10 UNC | 3A | 0.0000 | 0.6250 | 0.6163 | — | 0.5889 | 0.5854 | 0.5589 | 3B | 0.5650 | 0.5730 | 0.5889 | 0.5934 | 0.6250 | | | | |
| | 1A | 0.0018 | 0.7482 | 0.7288 | — | 0.6832 | 0.6744 | 0.6291 | 1B | 0.642 | 0.663 | 0.6850 | 0.6965 | 0.7500 | | | | |
| | 2A | 0.0018 | 0.7482 | 0.7353 | 0.7288 | 0.6832 | 0.6773 | 0.6291 | 2B | 0.642 | 0.663 | 0.6850 | 0.6927 | 0.7500 | | | | |
| $\frac{3}{4}$ -16 UNF | 3A | 0.0000 | 0.7500 | 0.7371 | — | 0.6850 | 0.6806 | 0.6309 | 3B | 0.6420 | 0.6545 | 0.6850 | 0.6907 | 0.7500 | | | | |
| | 1A | 0.0015 | 0.7485 | 0.7343 | — | 0.7079 | 0.7004 | 0.6740 | 1B | 0.682 | 0.696 | 0.7094 | 0.7192 | 0.7500 | | | | |
| | 2A | 0.0015 | 0.7485 | 0.7391 | — | 0.7079 | 0.7029 | 0.6740 | 2B | 0.682 | 0.696 | 0.7094 | 0.7159 | 0.7500 | | | | |
| $\frac{7}{8}$ -9 UNC | 3A | 0.0000 | 0.7500 | 0.7406 | — | 0.7094 | 0.7056 | 0.6755 | 3B | 0.6820 | 0.6908 | 0.7094 | 0.7143 | 0.7500 | | | | |
| | 1A | 0.0019 | 0.8731 | 0.8523 | — | 0.8009 | 0.7914 | 0.7408 | 1B | 0.755 | 0.778 | 0.8028 | 0.8151 | 0.8750 | | | | |
| | 2A | 0.0019 | 0.8731 | 0.8592 | 0.8523 | 0.8009 | 0.7946 | 0.7408 | 2B | 0.755 | 0.778 | 0.8028 | 0.8110 | 0.8750 | | | | |
| $\frac{7}{8}$ -9 UNC | 3A | 0.0000 | 0.8750 | 0.8611 | — | 0.8028 | 0.7981 | 0.7427 | 3B | 0.7550 | 0.7681 | 0.8028 | 0.8089 | 0.8750 | | | | |
| | 1A | 0.0016 | 0.8734 | 0.8579 | — | 0.8270 | 0.8189 | 0.7884 | 1B | 0.798 | 0.814 | 0.8286 | 0.8392 | 0.8750 | | | | |
| | 2A | 0.0016 | 0.8734 | 0.8631 | — | 0.8270 | 0.8216 | 0.7884 | 2B | 0.798 | 0.814 | 0.8286 | 0.8356 | 0.8750 | | | | |
| $\frac{7}{8}$ -14 UNF | 3A | 0.0000 | 0.8750 | 0.8647 | — | 0.8286 | 0.8245 | 0.7900 | 3B | 0.7980 | 0.8068 | 0.8286 | 0.8339 | 0.8750 | | | | |
| | 1A | 0.0020 | 0.9980 | 0.9755 | — | 0.9168 | 0.9067 | 0.8492 | 1B | 0.865 | 0.890 | 0.9188 | 0.9320 | 1.0000 | | | | |
| | 2A | 0.0020 | 0.9980 | 0.9830 | 0.9755 | 0.9168 | 0.9100 | 0.8492 | 2B | 0.865 | 0.890 | 0.9188 | 0.9276 | 1.0000 | | | | |
| 1-8 UNC | 3A | 0.0000 | 1.0000 | 0.9850 | — | 0.9188 | 0.9137 | 0.8512 | 3B | 0.8650 | 0.8797 | 0.9188 | 0.9254 | 1.0000 | | | | |
| | 1A | 0.0018 | 0.9982 | 0.9810 | — | 0.9441 | 0.9353 | 0.8990 | 1B | 0.910 | 0.928 | 0.9459 | 0.9573 | 1.0000 | | | | |
| | 2A | 0.0018 | 0.9982 | 0.9868 | — | 0.9441 | 0.9382 | 0.8990 | 2B | 0.910 | 0.928 | 0.9459 | 0.9535 | 1.0000 | | | | |
| 1-12 UNF | 3A | 0.0000 | 1.0000 | 0.9886 | — | 0.9459 | 0.9415 | 0.9008 | 3B | 0.9100 | 0.9198 | 0.9459 | 0.9516 | 1.0000 | | | | |

^aUse UNR designation instead of UN wherever UNR thread form is desired for external use.

^bThread classes may be combined; for example, a Class 2A external thread may be used with a Class 1B, 2B, or 3B internal thread.

^cUN series external thread maximum minor diameter is basic for Class 3A and basic minus allowance for Classes 1A and 2A.

^dFor Class 2A threads having an additive finish the maximum is increased, by the allowance, to the basic size, the value being the same as for Class 3A.

^eFor unfinished hot-rolled material not including standard fasteners with rolled threads.

All dimensions are in inches.

For UNS threads and sizes above 1 inch see ASME/ANSI B1.1-1989 (R2001). Use UNS threads only if Standard Series do not meet requirements.

Table 3. External Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2A

| Characteristic Description | Calculation | Notes |
|---|--|---|
| Basic major diameter, d_{bsc} | $d_{bsc} = \frac{1}{2} = 0.5 = 0.5000$ | d_{bsc} is rounded to four decimal places |
| Pitch, P | $P = \frac{1}{28} = 0.035714285714 = 0.03571429$ | P is rounded to eight decimal places |
| Maximum external major diameter (d_{max}) = basic major diameter (d_{bsc}) – allowance (es) | $d_{max} = d_{bsc} - es$ | es is the basic allowance |
| Basic major diameter (d_{bsc}) | $d_{bsc} = 0.5000$ | d_{bsc} is rounded to four decimal places |
| Allowance (es) | $es = 0.300 \times Td_2$ for Class 2A | Td_2 is the pitch diameter tolerance for Class 2A |
| External pitch diameter tolerance Td_2 | $Td_2 = 0.0015D^{\frac{1}{3}} + 0.0015\sqrt{LE} + 0.015P^{\frac{2}{3}}$ $= 0.0015 \times 0.5^{\frac{1}{3}} + 0.0015\sqrt{9 \times 0.03571429} + 0.015(0.03571429)^{\frac{2}{3}}$ $= 0.001191 + 0.000850 + 0.001627 = 0.003668$ | $LE = 9P$ (length of engagement) Td_2 is rounded to six decimal places |
| Allowance (es) | $es = 0.300 \times 0.003668 = 0.0011004 = 0.0011$ | es is rounded to four decimal places |
| Maximum external major diameter (d_{max}) | $d_{max} = d_{base} - es = 0.5000 - 0.0011 = 0.4989$ | d_{max} is rounded to four decimal places |
| Minimum external major diameter (d_{min}) = maximum external major diameter (d_{max}) – major diameter tolerance (Td) | $d_{min} = d_{max} - Td$ | Td is the major diameter tolerance |
| Major diameter tolerance (Td) | $Td = 0.060\sqrt[3]{P^2} = 0.060 \times \sqrt[3]{0.03571429^2}$ $= 0.060 \times \sqrt[3]{0.001276} = 0.060 \times 0.108463$ $= 0.00650778 = 0.0065$ | Td is rounded to four decimal places |

Table 3. (Continued) External Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2A

| Characteristic Description | Calculation | Notes |
|--|---|---|
| Minimum external major diameter (d_{min}) | $d_{min} = d_{max} - Td = 0.4989 - 0.006508 \\ = 0.492392 = 0.4924$ | d_{min} is rounded to four decimal places |
| Maximum external pitch diameter (d_{2max}) = maximum external major diameter (d_{max}) – twice the external thread addendum (h_{as}) | $d_{2max} = d_{max} - 2 \times h_{as}$ | h_{as} = external thread addendum |
| External thread addendum | $h_{as} = \frac{0.64951905P}{2} \quad 2h_{as} = 0.64951905P \\ 2h_{as} = 0.64951905 \times 0.03571429 = 0.02319711 \\ = 0.023197$ | $2h_{as}$ is rounded to six decimal places |
| Maximum external pitch diameter (d_{2max}) | $d_{2max} = d_{max} - 2 \times h_{as} = 0.4989 - 0.23197 \\ = 0.475703 = 0.4757$ | d_{2max} is rounded to four decimal places |
| Minimum external pitch diameter (d_{2min}) = maximum external pitch diameter (d_{2max}) – external pitch diameter tolerance (Td_2) | $d_{2min} = d_{2max} - Td_2$ | Td_2 = external pitch diameter tolerance (see previous Td_2 calculation in this table) |
| Minimum external pitch diameter (d_{2min}) | $d_{2min} = d_{2max} - Td_2 = 0.4757 - 0.003668 \\ = 0.472032 = 0.4720$ | d_{2min} is rounded to four decimal places |
| Maximum external UNR minor diameter (d_{3max}) = maximum external major diameter (d_{max}) – double height of external UNR thread $2h_s$ | $d_{3max} = d_{max} - 2 \times h_s$ | h_s = external UNR thread height, |
| External UNR thread height ($2h_s$) | $2h_s = 1.19078493P = 1.19078493 \times 0.03571429 \\ = 0.042528$ | $2h_s$ rounded to six decimal places |
| Maximum external UNR minor diameter (d_{3max}) | $d_{3max} = d_{max} - 2 \times h_s = 0.4989 - 0.042528 \\ = 0.456372 = 0.4564$ | d_{3max} is rounded to four decimal places |

Table 3. (Continued) External Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2A

| Characteristic Description | Calculation | Notes |
|--|--|--|
| Maximum external UN minor diameter (d_{1max}) = maximum external major diameter (d_{max}) – double height of external UN thread $2h_s$ | $d_{1max} = d_{max} - 2 \times h_s$ | For UN threads, $2h_s = 2h_n$ |
| Double height of external UN thread $2h_s$ | $\begin{aligned} 2h_s &= 1.08253175P \\ &= 1.08253175 \times 0.03571429 = 0.03866185 \\ &= 0.038662 \end{aligned}$ | $2h_s$ is rounded to six decimal places |
| Maximum external UN minor diameter (d_{1max}) | $\begin{aligned} d_{1max} &= d_{max} - 2 \times h_s \\ &= 0.4989 - 0.038662 = 0.460238 = 0.4602 \end{aligned}$ | d_{1max} is rounded to four decimal places |
| | | |

Table 4. Internal Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2B

| Characteristic Description | Calculation | Notes |
|--|--|--|
| Basic major diameter, d_{bsc} | $d_{bsc} = \frac{1}{2} = 0.5 = 0.5000$ | d_{bsc} is rounded to four decimal places |
| Pitch, P | $P = \frac{1}{28} = 0.035714285714 = 0.03571429$ | P is rounded to eight decimal places |
| Minimum internal minor diameter (D_{1min}) = basic major diameter (D_{bsc}) – double height of external UN thread $2h_n$ | $D_{1min} = D_{bsc} - 2h_n$ | $2h_n$ is the double height of external UN thread |
| Double height of external UN thread $2h_s$ | $\begin{aligned} 2h_n &= 1.08253175P = 1.08253175 \times 0.03571429 \\ &= 0.03866185 = 0.038662 \end{aligned}$ | $2h_n$ is rounded to six decimal places |
| Minimum internal major diameter (D_{1min}) | $\begin{aligned} D_{1min} &= D_{bsc} - 2 \times h_n = 0.5000 - 0.038662 \\ &= 0.461338 = 0.461 \end{aligned}$ | For class 2B the value is rounded to three decimal places to obtain the final values |

Table 4. (Continued) Internal Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2B

| Characteristic Description | Calculation | Notes |
|--|--|---|
| Maximum internal minor diameter (D_{1max}) = minimum internal minor diameter (D_{1min}) + internal minor diameter tolerance TD_1 | $D_{1max} = D_{1min} + TD_1$ | D_{1min} is rounded to six decimal places |
| Internal minor diameter tolerance TD_1 | $TD_1 = 0.25P - 0.40P^2$ $= 0.25 \times 0.03571429 - 0.40 \times 0.03571429^2$ $= 0.008929 - 0.000510 = 0.008419 = 0.003127$ | TD_1 is rounded to four decimal places. |
| Maximum internal minor diameter (D_{1max}) | $D_{1max} = D_{1min} + TD_1 = 0.461338 + 0.008419$ $= 0.469757 = 0.470$ | For the Class 2B thread D_{1max} is rounded to three decimal places to obtain final values. Other sizes and classes are expressed in a four decimal places |
| Minimum internal pitch diameter (D_{2min}) = basic major diameter (D_{bsc}) – twice the external thread addendum (h_b) | $D_{2min} = D_{bsc} - h_b$ | h_b = external thread addendum |
| External thread addendum (h_b) | $h_b = 0.64951905P = 0.64951905 \times 0.03571429$ $= 0.02319711 = 0.023197$ | h_b is rounded to six decimal places |
| Minimum internal pitch diameter (D_{2min}) | $D_{2min} = D_{bsc} - h_b = 0.5000 - 0.023197$ $= 0.476803 = 0.4768$ | D_{2min} is rounded to four decimal places |
| Maximum internal pitch diameter (D_{2max}) = minimum internal pitch diameter (D_{2min}) + internal pitch diameter tolerance (TD_2) | $D_{2max} = D_{2min} + TD_2$ | TD_2 = external pitch diameter tolerance |
| External pitch diameter tolerance TD_2 | $TD_2 = 1.30 \times (Td_2 \text{ for Class 2A}) = 1.30 \times 0.003668$ $= 0.0047684 = 0.0048$ | Constant 1.30 is for this Class 2B example, and will be different for Classes 1B and 3B. Td_2 for Class 2A (see Table 3) is rounded to six decimal places. TD_2 is rounded 4 to places |
| Maximum internal pitch diameter (D_{2max}) | $D_{2max} = D_{2min} + TD_2 = 0.4768 + 0.0048 = 0.4816$ | D_{2max} is rounded to four decimal places |

Table 4. (Continued) Internal Inch Screw Thread Calculations for $\frac{1}{2}$ -28 UNEF-2B

| Characteristic Description | Calculation | Notes |
|---|------------------------------|---|
| Minimum internal major diameter (D_{min}) = basic major diameter (D_{bsc}) | $D_{min} = D_{bsc} = 0.5000$ | D_{min} is rounded to four decimal places |

Table 5. External Inch Screw Thread Calculations for $\frac{1}{2}_{64}$ -36 UNS-2A

| Characteristic Description | Calculation | Notes |
|---|--|---|
| Basic major diameter, d_{bsc} | $d_{bsc} = \frac{19}{64} = 0.296875 = 0.2969$ | d_{bsc} is rounded to four decimal places |
| Pitch, P | $P = \frac{1}{36} = 0.027777777778 = 0.02777778$ | P is rounded to eight decimal places |
| Maximum external major diameter (d_{max}) = basic major diameter (d_{bsc}) – allowance (es) | $d_{max} = d_{bsc} - es$ | |
| Allowance (es) | $es = 0.300 \times Td_2$ for Class 2A | Td_2 is Pitch diameter tolerance for Class 2A |
| External pitch diameter tolerance, Td_2 | $Td_2 = 0.0015D^{\frac{1}{3}} + 0.0015\sqrt{LE} + 0.015P^{\frac{2}{3}}$ $= 0.0015 \times 0.2969^{\frac{1}{3}} + 0.0015\sqrt{9 \times 0.02777778} + 0.015(0.02777778)^{\frac{2}{3}}$ $= 0.001000679 + 0.00075 + 0.001375803 = 0.003126482$ $= 0.003127$ | $LE = 9P$ (length of engagement) Td_2 is rounded to six decimal places |
| Allowance (es) | $es = 0.300 \times 0.003127 = 0.0009381 = 0.0009$ | es is rounded to four decimal places |
| Maximum external major diameter (d_{max}) | $d_{max} = d_{bsc} - es = 0.2969 - 0.0009 = 0.2960$ | d_{max} is rounded to four decimal places |

Table 5.(Continued) External Inch Screw Thread Calculations for $1\frac{1}{64}$ -36 UNS-2A

| Characteristic Description | Calculation | Notes |
|--|---|--|
| Minimum external major diameter (d_{min}) = maximum external major diameter (d_{max}) – major diameter tolerance (Td) | $d_{min} = d_{max} - Td$ | Td is the major diameter tolerance |
| Major diameter tolerance (Td) | $\begin{aligned} Td &= 0.060 \sqrt[3]{P^2} = 0.060 \times \sqrt[3]{0.02777778^2} \\ &= 0.060 \times \sqrt[3]{0.000772} = 0.060 \times 0.091736 \\ &= 0.00550416 = 0.0055 \end{aligned}$ | Td is rounded to four decimal places |
| Minimum external major diameter (d_{min}) | $d_{min} = d_{max} - Td = 0.2960 - 0.0055 = 0.2905$ | d_{min} is rounded to four decimal places |
| Maximum external pitch diameter (d_{2max}) = maximum external major diameter (d_{max}) – twice the external thread addendum | $d_{2max} = d_{max} - 2 \times h_{as}$ | h_{as} = external thread addendum |
| External thread addendum | $\begin{aligned} h_{as} &= \frac{0.64951905P}{2} \quad 2h_{as} = 0.64951905P \\ 2h_{as} &= 0.64951905 \times 0.02777778 = 0.0180421972 \\ &= 0.018042 \end{aligned}$ | h_{as} is rounded to six decimal places |
| Maximum external pitch diameter (d_{2max}) | $\begin{aligned} d_{2max} &= d_{max} - 2h_{as} = 0.2960 - 0.018042 \\ &= 0.277958 = 0.2780 \end{aligned}$ | d_{2max} is rounded to four decimal places |
| Minimum external pitch diameter (d_{2min}) = maximum external pitch diameter (d_{2max}) – external pitch diameter tolerance (Td_2) | $d_{2min} = d_{2max} - Td_2$ | Td_2 = external pitch diameter tolerance (see previous Td_2 calculation in this table) |
| Minimum external pitch diameter (d_{2min}) | $\begin{aligned} d_{2min} &= d_{2max} - Td_2 = 0.2780 - 0.003127 \\ &= 0.274873 = 0.2749 \end{aligned}$ | d_{2min} is rounded to four decimal places |

Table 5. (Continued) External Inch Screw Thread Calculations for $\frac{19}{64}$ -36 UNS-2A

| Characteristic Description | Calculation | Notes |
|--|---|--|
| Maximum external UNR minor diameter (d_{3max}) = maximum external major diameter (d_{max}) – double height of external UNR thread $2h_s$ | $d_{3max} = d_{max} - 2h_s$ | h_s = external UNR thread height, |
| External UNR thread height | $2h_s = 1.19078493P = 1.19078493 \times 0.02777778$ $= 0.033077362 = 0.033077$ | $2h_s$ is rounded to six decimal places |
| Maximum external UNR minor diameter (d_{3max}) | $d_{3max} = d_{max} - 2h_s = 0.2960 - 0.033077$ $= 0.262923 = 0.2629$ | d_{3max} is rounded to four decimal places |
| Maximum external UN minor diameter (d_{1max}) = maximum external major diameter (d_{max}) – double height of external UN thread $2h_s$ | $d_{1max} = d_{max} - 2 \times h_s$ | For UN threads, $2h_s = 2h_n$ |
| Double height of external UN thread $2h_s$ | $2h_s = 1.08253175P = 1.08253175 \times 0.02777778$ $= 0.030070329 = 0.030070$ | For UN threads, $2h_s = 2h_n$ $2h_s$ is rounded to six decimal places |
| Maximum external UN minor diameter (d_{1max}) | $d_{1max} = d_{max} - 2h_s = 0.2960 - 0.030070$ $= 0.265930 = 0.2659$ | Maximum external UN minor diameter is rounded to four decimal places |

Table 6. Internal Inch Screw Thread Calculations for $\frac{19}{64}$ -28 UNS-2B

| Characteristic Description | Calculation | Notes |
|--|---|--|
| Minimum internal minor diameter (D_{1min}) = basic major diameter (D_{bsc}) – double height of external UN thread $2h_n$ | $D_{1min} = D_{bsc} - 2h_n$ | $2h_n$ is the double height of external UN threads |
| Basic major diameter (D_{bsc}) | $D_{bsc} = \frac{19}{64} = 0.296875 = 0.2969$ | This is the final value of basic major diameter (given) and rounded to four decimal places |

Table 6. (Continued) Internal Inch Screw Thread Calculations for 19/64-28 UNS-2B

| Characteristic Description | Calculation | Notes |
|--|--|---|
| Double height of external UN thread $2h_s$ | $2h_n = 1.08253175P = 1.08253175 \times 0.02777778 \\ = 0.030070329 = 0.030070$ | P is rounded to eight decimal places |
| Minimum internal major diameter (D_{1min}) | $D_{1min} = D_{bsc} - 2h_n = 0.2969 - 0.030070 \\ = 0.266830 = 0.267$ | For class 2B the value is rounded to three decimal places to obtain the final value, other sizes and classes are expressed in a four place decimal. |
| Maximum internal minor diameter (D_{1max}) = minimum internal minor diameter (D_{1min}) + internal minor diameter tolerance TD_1 | $D_{1max} = D_{1min} + TD_1$ | D_{1min} is rounded to six decimal places |
| Internal minor diameter tolerance TD_1 | $TD_1 = 0.25P - 0.40P^2 \\ = 0.25 \times 0.02777778 - 0.40 \times 0.02777778^2 \\ = 0.006944 - 0.000309 = 0.006635 = 0.0066$ | TD_1 is rounded to four decimal places. |
| Maximum internal minor diameter (D_{1max}) | $D_{1max} = D_{1min} + TD_1 = 0.266830 + 0.006635 \\ = 0.273465 = 0.273$ | For Class 2B thread the value is rounded to three decimal places to obtain the final values. Other sizes and classes are expressed in a four decimal places |
| Minimum internal pitch diameter (D_{2min}) = basic major diameter (D_{bsc}) – twice the external thread addendum (h_b) | $D_{2min} = D_{1max} - h_b$ | h_b = external thread addendum |
| External thread addendum | $h_b = 0.64951905P = 0.64951905 \times 0.02777778 \\ = 0.018042197 = 0.018042$ | h_b is rounded to six decimal places |
| Minimum internal pitch diameter (D_{2min}) | $D_{2min} = D_{bsc} - h_b = 0.2969 - 0.018042 \\ = 0.278858 = 0.2789$ | D_{2min} is rounded to four decimal places |
| Maximum internal pitch diameter (D_{2max}) = minimum internal pitch diameter (D_{2min}) + internal pitch diameter tolerance (TD_2) | $D_{2max} = D_{2min} + TD_2$ | TD_2 = external pitch diameter tolerance |

Table 6. (Continued) Internal Inch Screw Thread Calculations for $1\frac{9}{64}$ -28 UNS-2B

| Characteristic Description | Calculation | Notes |
|---|---|---|
| External pitch diameter tolerance TD_2 | $TD_2 = 1.30 \times (Td_2 \text{ for Class 2A})$ $= 1.30 \times 0.003127 = 0.0040651 = 0.0041$ | The constant 1.30 is for this Class 2B example, and will be different for Classes 1B and 3B. Td_2 for Class 2A (see calculation, Table 5) is rounded to six decimal places |
| Maximum internal pitch diameter (D_{2max}) | $D_{2max} = D_{2min} + TD_2 = 0.2789 + 0.0041 = 0.2830$ | D_{2max} is rounded to four decimal places |
| Minimum internal major diameter (D_{min}) = basic major diameter (D_{bsc}) | $D_{min} = D_{bsc} = 0.2969$ | D_{min} is rounded to four decimal places |

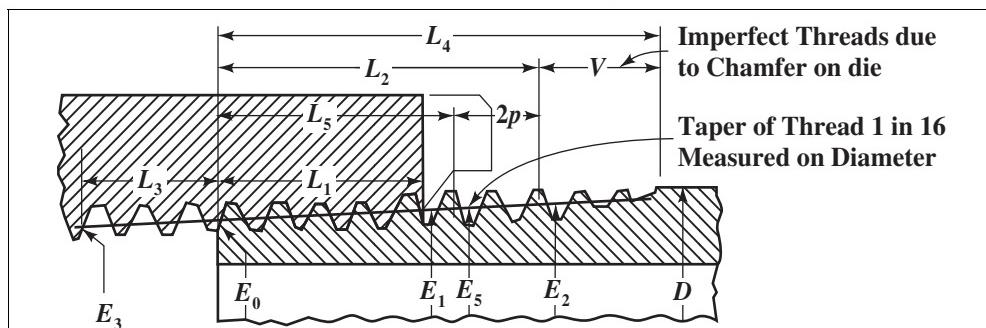
Table 7. Number of Decimal Places for Intermediate and Final Calculations of Thread Characteristics

| Symbol | Dimensions | Intermediate | | Final | | Symbol | Dimensions | Intermediate | | Final | |
|-----------------------|---|--------------|--------|-------|--------|--|---|--------------|--------|-------|-------------------|
| | | Inch | Metric | Inch | Metric | | | Inch | Metric | Inch | Metric |
| <i>d</i> | Major diameter, external thread | ... | ... | 4 | 3 | <i>LE</i> | Length of thread engagement | 6 | N/A | ... | ... |
| <i>D</i> | Major diameter, internal thread | ... | ... | 4 | 3 | <i>P</i> | Pitch | ... | ... | 8 | Note ^a |
| <i>d</i> ₂ | Pitch diameter, external thread | ... | ... | 4 | 3 | <i>Td</i> | Major diameter tolerance | ... | ... | 4 | 3 |
| <i>D</i> ₂ | Pitch diameter, internal thread | ... | ... | 4 | 3 | <i>Td</i> ₂ | Pitch diameter tolerance, external thread | ... | ... | 6 | 3 |
| <i>d</i> ₁ | Minor diameter, external thread | ... | ... | 4 | 3 | <i>TD</i> ₂ | Pitch diameter tolerance, internal thread | ... | ... | 4 | 3 |
| <i>d</i> ₃ | Minor diameter, rounded root external thread | ... | ... | 4 | 3 | <i>TD</i> ₁ | Minor diameter tolerance, internal thread | ... | ... | 4 | 3 |
| <i>D</i> ₁ | Minor diameter, internal threads for sizes 0.138 and larger for Classes 1B and 2B only | ... | ... | 3 | N/A | <i>h</i> _b = 2 <i>h</i> _{as} | Twice the external thread addendum | 6 | N/A | ... | ... |
| <i>D</i> ₁ | Minor diameter, internal threads for sizes smaller than 0.138 for Classes 1B and 2B, and all sizes for Class 3B | ... | ... | 4 | N/A | <i>2h</i> _s | Double height of UNR external thread | 6 | N/A | ... | ... |
| <i>D</i> ₁ | Minor diameter, internal metric thread | ... | ... | N/A | 3 | <i>2h</i> _n | Double height of internal thread and UN external thread | 6 | N/A | ... | ... |
| <i>es</i> | Allowance at major pitch and minor diameters of external thread | ... | ... | | 3 | | Twice the external thread addendum | 6 | N/A | ... | ... |

^aMetric pitches are not calculated. They are stated in the screw thread designation and are to be used out to the number of decimal places as stated.

Note: Constants based on a function of P are rounded to an 8-place decimal for inch threads and a 7-place decimal for metric threads.

**Table 8. Basic Dimensions, American National Standard Taper Pipe Threads, NPT
ANSI/ASME B1.20.1-1983, R2006**



For all dimensions, see corresponding reference letter in table.

Angle between sides of thread is 60 degrees. Taper of thread, on diameter, is $\frac{1}{4}$ inch per foot. Angle of taper with center line is $1^\circ 47'$.

The basic maximum thread height, h , of the truncated thread is $0.8 \times$ pitch of thread. The crest and root are truncated a minimum of $0.033 \times$ pitch for all pitches.

| Nominal Pipe Size | Outside Dia. of Pipe, D | Threads per Inch, n | Pitch of Thread, p | Pitch Diameter at Beginning of External Thread, E_0 | Handtight Engagement | | Effective Thread, External | |
|-------------------|---------------------------|-----------------------|----------------------|---|----------------------------|--------------------------|----------------------------|--------------------------|
| | | | | | Length, ^a L_1 | Dia., ^b E_1 | Length, ^c L_2 | Dia., ^c E_2 |
| | | | | | | | | |
| $\frac{1}{16}$ | 0.3125 | 27 | 0.03704 | 0.27118 | 0.160 | 0.28118 | 0.2611 | 0.28750 |
| $\frac{1}{8}$ | 0.405 | 27 | 0.03704 | 0.36351 | 0.1615 | 0.37360 | 0.2639 | 0.38000 |
| $\frac{1}{4}$ | 0.540 | 18 | 0.05556 | 0.47739 | 0.2278 | 0.49163 | 0.4018 | 0.50250 |
| $\frac{3}{8}$ | 0.675 | 18 | 0.05556 | 0.61201 | 0.240 | 0.62701 | 0.4078 | 0.63750 |
| $\frac{1}{2}$ | 0.840 | 14 | 0.07143 | 0.75843 | 0.320 | 0.77843 | 0.5337 | 0.79179 |
| $\frac{3}{4}$ | 1.050 | 14 | 0.07143 | 0.96768 | 0.339 | 0.98887 | 0.5457 | 1.00179 |
| 1 | 1.315 | $1\frac{1}{2}$ | 0.08696 | 1.21363 | 0.400 | 1.23863 | 0.6828 | 1.25630 |
| $1\frac{1}{4}$ | 1.660 | $1\frac{1}{2}$ | 0.08696 | 1.55713 | 0.420 | 1.58338 | 0.7068 | 1.60130 |
| $1\frac{1}{2}$ | 1.900 | $1\frac{1}{2}$ | 0.08696 | 1.79609 | 0.420 | 1.82234 | 0.7235 | 1.84130 |
| 2 | 2.375 | $1\frac{1}{2}$ | 0.08696 | 2.26902 | 0.436 | 2.29627 | 0.7565 | 2.31630 |
| $2\frac{1}{2}$ | 2.875 | 8 | 0.12500 | 2.71953 | 0.682 | 2.76216 | 1.1375 | 2.79062 |
| 3 | 3.500 | 8 | 0.12500 | 3.34062 | 0.766 | 3.38850 | 1.2000 | 3.41562 |
| $3\frac{1}{2}$ | 4.000 | 8 | 0.12500 | 3.83750 | 0.821 | 3.88881 | 1.2500 | 3.91562 |
| 4 | 4.500 | 8 | 0.12500 | 4.33438 | 0.844 | 4.38712 | 1.3000 | 4.41562 |
| 5 | 5.563 | 8 | 0.12500 | 5.39073 | 0.937 | 5.44929 | 1.4063 | 5.47862 |
| 6 | 6.625 | 8 | 0.12500 | 6.44609 | 0.958 | 6.50597 | 1.5125 | 6.54062 |
| 8 | 8.625 | 8 | 0.12500 | 8.43359 | 1.063 | 8.50003 | 1.7125 | 8.54062 |
| 10 | 10.750 | 8 | 0.12500 | 10.54531 | 1.210 | 10.62094 | 1.9250 | 10.66562 |
| 12 | 12.750 | 8 | 0.12500 | 12.53281 | 1.360 | 12.61781 | 2.1250 | 12.66562 |
| 14 OD | 14.000 | 8 | 0.12500 | 13.77500 | 1.562 | 13.87262 | 2.2500 | 13.91562 |
| 16 OD | 16.000 | 8 | 0.12500 | 15.76250 | 1.812 | 15.87575 | 2.4500 | 15.91562 |
| 18 OD | 18.000 | 8 | 0.12500 | 17.75000 | 2.000 | 17.87500 | 2.6500 | 17.91562 |
| 20 OD | 20.000 | 8 | 0.12500 | 19.73750 | 2.125 | 19.87031 | 2.8500 | 19.91562 |
| 24 OD | 24.000 | 8 | 0.12500 | 23.71250 | 2.375 | 23.86094 | 3.2500 | 23.91562 |

^a Also length of thin ring gage and length from gaging notch to small end of plug gage.

^b Also pitch diameter at gaging notch (handtight plane).

^c Also length of plug gage.

**Table 9. Basic Dimensions, American National Standard Taper Pipe Threads, NPT
ANSI/ASME B1.20.1-1983, R2006**

| Nominal Pipe Size | Wrench Makeup Length for Internal Thread | | Vanish Thread, (3.47 thds.), V | Overall Length External Thread, L ₄ | Nominal Perfect External Threads ^a | | Height of Thread, h | Basic Minor Dia. at Small End of Pipe ^b , K ₀ |
|-------------------|--|----------------------|--------------------------------|--|---|----------------------|---------------------|---|
| | Length, L ₃ | Dia., E ₃ | | | Length, L ₅ | Dia., E ₅ | | |
| 1/16 | 0.1111 | 0.26424 | 0.1285 | 0.3896 | 0.1870 | 0.28287 | 0.02963 | 0.2416 |
| 1/8 | 0.1111 | 0.35656 | 0.1285 | 0.3924 | 0.1898 | 0.37537 | 0.02963 | 0.3339 |
| 1/4 | 0.1667 | 0.46697 | 0.1928 | 0.5946 | 0.2907 | 0.49556 | 0.04444 | 0.4329 |
| 3/8 | 0.1667 | 0.60160 | 0.1928 | 0.6006 | 0.2967 | 0.63056 | 0.04444 | 0.5676 |
| 1/2 | 0.2143 | 0.74504 | 0.2478 | 0.7815 | 0.3909 | 0.78286 | 0.05714 | 0.7013 |
| 3/4 | 0.2143 | 0.95429 | 0.2478 | 0.7935 | 0.4029 | 0.99286 | 0.05714 | 0.9105 |
| 1 | 0.2609 | 1.19733 | 0.3017 | 0.9845 | 0.5089 | 1.24543 | 0.06957 | 1.1441 |
| 1 1/4 | 0.2609 | 1.54083 | 0.3017 | 1.0085 | 0.5329 | 1.59043 | 0.06957 | 1.4876 |
| 1 1/2 | 0.2609 | 1.77978 | 0.3017 | 1.0252 | 0.5496 | 1.83043 | 0.06957 | 1.7265 |
| 2 | 0.2609 | 2.25272 | 0.3017 | 1.0582 | 0.5826 | 2.30543 | 0.06957 | 2.1995 |
| 2 1/2 | 0.2500 ^d | 2.70391 | 0.4337 | 1.5712 | 0.8875 | 2.77500 | 0.100000 | 2.6195 |
| 3 | 0.2500 ^d | 3.32500 | 0.4337 | 1.6337 | 0.9500 | 3.40000 | 0.100000 | 3.2406 |
| 3 1/2 | 0.2500 | 3.82188 | 0.4337 | 1.6837 | 1.0000 | 3.90000 | 0.100000 | 3.7375 |
| 4 | 0.2500 | 4.31875 | 0.4337 | 1.7337 | 1.0500 | 4.40000 | 0.100000 | 4.2344 |
| 5 | 0.2500 | 5.37511 | 0.4337 | 1.8400 | 1.1563 | 5.46300 | 0.100000 | 5.2907 |
| 6 | 0.2500 | 6.43047 | 0.4337 | 1.9462 | 1.2625 | 6.52500 | 0.100000 | 6.3461 |
| 8 | 0.2500 | 8.41797 | 0.4337 | 2.1462 | 1.4625 | 8.52500 | 0.100000 | 8.3336 |
| 10 | 0.2500 | 10.52969 | 0.4337 | 2.3587 | 1.6750 | 10.65000 | 0.100000 | 10.4453 |
| 12 | 0.2500 | 12.51719 | 0.4337 | 2.5587 | 1.8750 | 12.65000 | 0.100000 | 12.4328 |
| 14 OD | 0.2500 | 13.75938 | 0.4337 | 2.6837 | 2.0000 | 13.90000 | 0.100000 | 13.6750 |
| 16 OD | 0.2500 | 15.74688 | 0.4337 | 2.8837 | 2.2000 | 15.90000 | 0.100000 | 15.6625 |
| 18 OD | 0.2500 | 17.73438 | 0.4337 | 3.0837 | 2.4000 | 17.90000 | 0.100000 | 17.6500 |
| 20 OD | 0.2500 | 19.72188 | 0.4337 | 3.2837 | 2.6000 | 19.90000 | 0.100000 | 19.6375 |
| 24 OD | 0.2500 | 23.69688 | 0.4337 | 3.6837 | 3.0000 | 23.90000 | 0.100000 | 23.6125 |

^aThe length L₅ from the end of the pipe determines the plane beyond which the thread form is imperfect at the crest. The next two threads are perfect at the root. At this plane the cone formed by the crests of the thread intersects the cylinder forming the external surface of the pipe. $L_5 = L_2 - 2p$.

^bGiven as information for use in selecting tap drills.

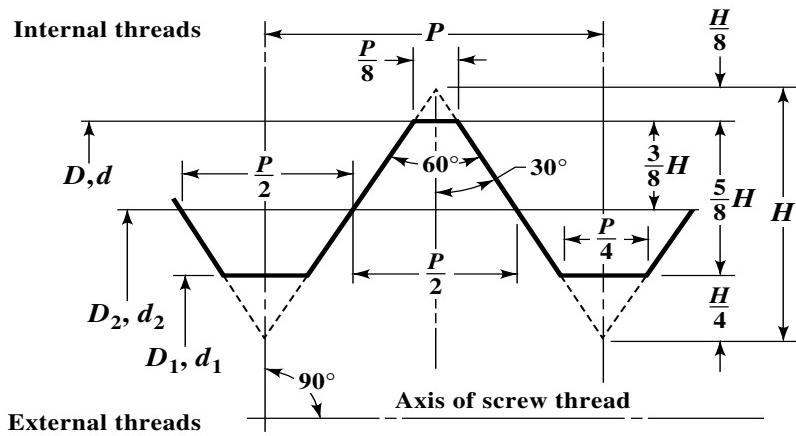
^cThree threads for 2-inch size and smaller; two threads for larger sizes.

^dMilitary Specification MIL-P-7105 gives the wrench makeup as three threads for 3 in. and smaller. The E₃ dimensions are then as follows: Size 2 1/2 in., 2.69609 and size 3 in., 3.31719.

All dimensions given in inches.

Increase in diameter per thread is equal to 0.0625/n.

The basic dimensions of the ANSI Standard Taper Pipe Thread are given in inches to four or five decimal places. While this implies a greater degree of precision than is ordinarily attained, these dimensions are the basis of gage dimensions and are so expressed for the purpose of eliminating errors in computations.

Metric Screw Threads M-Profile

$$H = \frac{\sqrt{3}}{2} \times P = 0.866025P$$

$$0.125H = 0.108253P \quad 0.250H = 0.216506P \quad 0.375H = 0.324760P \quad 0.625H = 0.541266P$$

Fig. 1. Basic M Thread Profile ISO 68 Basic Profile

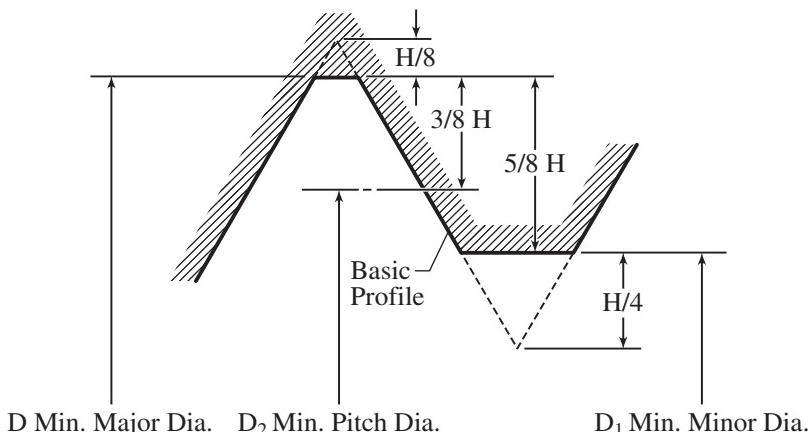


Fig. 2. Internal Thread Design M Profile with No Allowance (Fundamental Deviation) (Maximum Material Condition). For Dimensions see Table 10

Definitions.— The following definitions apply to metric screw threads — M profile.

Basic Thread Profile: The cyclical outline in an axial plane of the permanently established boundary between the provinces of the external and internal threads. All deviations are with respect to this boundary. (See Fig. 1 and 4.)

Design Profiles: The maximum material profiles permitted for external and internal threads for a specified tolerance class. (See Fig. 2 and 3.)

Fundamental Deviation: For Standard threads, the deviation (upper or lower) closer to the basic size. It is the upper deviation, es , for an external thread and the lower deviation, EI , for an internal thread. (See Fig. 4.)

Limiting Profiles: The limiting M profile for internal threads is shown in Fig. 5. The limiting M profile for external threads is shown in Fig. 6.

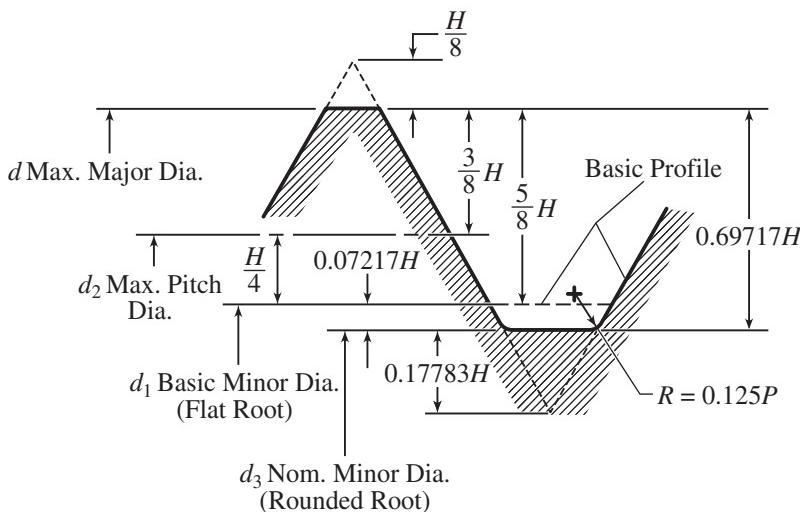


Fig. 3. External Thread Design M Profile with No Allowance (Fundamental Deviation) (Flanks at Maximum Material Condition). For Dimensions see Table 10

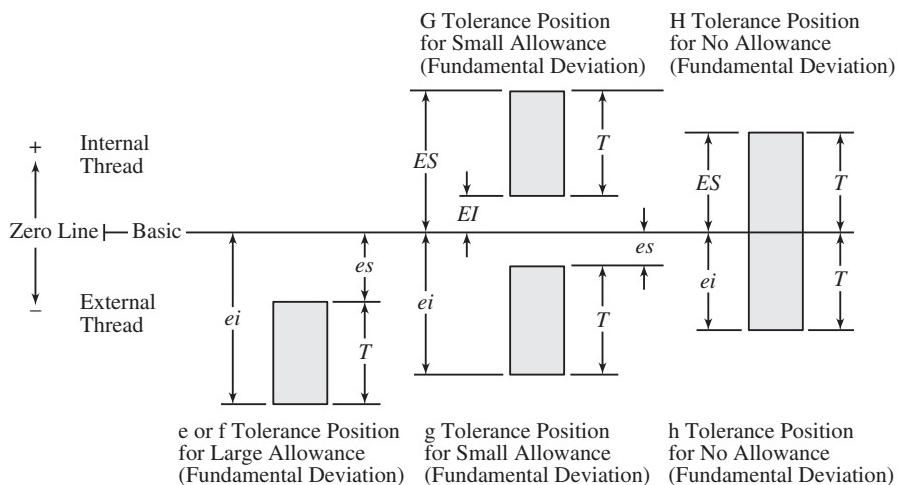


Fig. 4. Metric Tolerance System for Screw Threads

Formulas for M Profile Screw Thread Limiting Dimensions.—The limiting dimensions for M profile screw threads are calculated from the following formulas.

Internal Threads:

$$\text{Min major dia.} = \text{basic major dia.} + EI$$

$$\text{Min pitch dia.} = \text{basic major dia.} - 0.6495191P + EI \text{ for } D_2$$

$$\text{Max pitch dia.} = \text{min pitch dia.} + TD_2$$

$$\text{Max major dia.} = \text{max pitch dia.} + 0.7938566P$$

$$\text{Min minor dia.} = \text{min major dia.} - 1.0825318P$$

$$\text{Max minor dia.} = \text{min minor dia.} + TD_1$$

External Threads:

$$\text{Max major dia.} = \text{basic major dia.} - es \text{ (Note that } es \text{ is an absolute value.)}$$

$$\text{Min major dia.} = \text{max major dia.} - Td$$

$$\text{Max pitch dia.} = \text{basic major dia.} - 0.6495191P - es \text{ for } d_2$$

$$\text{Min pitch dia.} = \text{max pitch dia.} - Td_2$$

Max flat form minor dia. = max pitch dia. - 0.433013P

Max rounded root minor dia. = max pitch dia. - 2 × max trunc.

Min rounded root minor dia. = min pitch dia. - 0.616025P

Min root radius = 0.125P

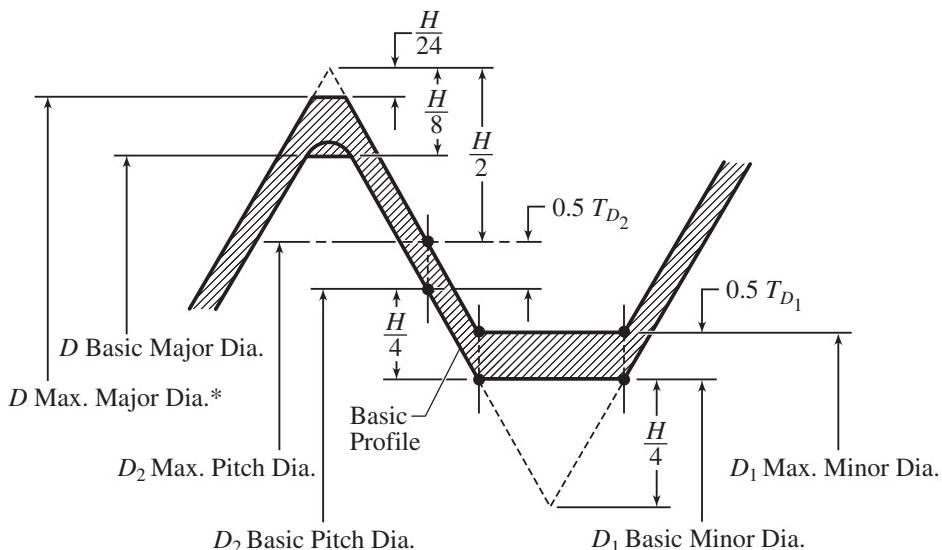


Fig. 5. Internal Thread — Limiting M Profile. Tolerance Position H

*This dimension is used in the design of tools, etc. In dimensioning internal threads it is not normally specified. Generally, major diameter acceptance is based on maximum material condition gaging.

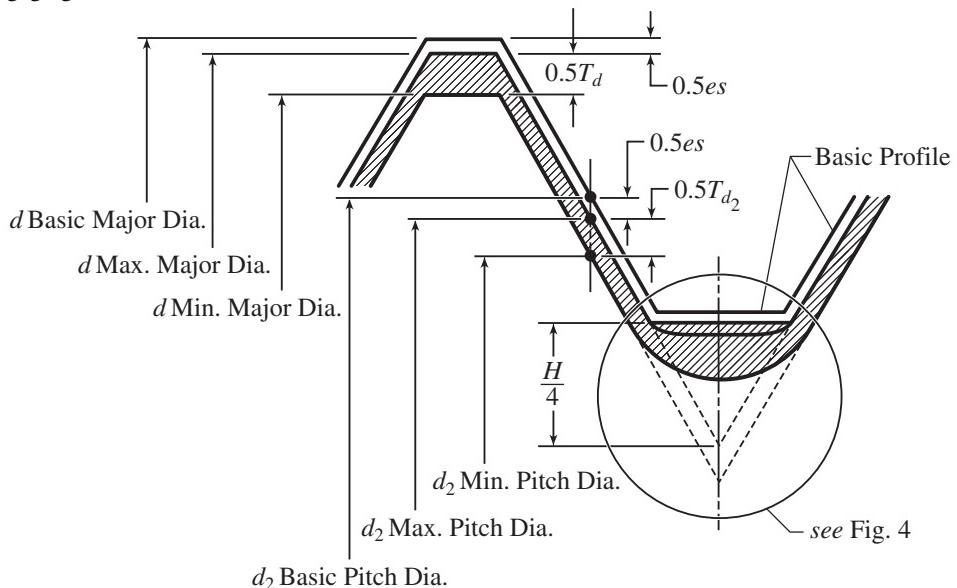


Fig. 6. External Thread — Limiting M Profile. Tolerance Position g

Table 10. American National Standard Metric Thread — M Profile Data ANSI/ASME B1.13M-2001

| Pitch <i>P</i> | Truncation of Internal Thread Root and External Thread Crest $\frac{H}{8}$ 0.1082532 <i>P</i> | Addendum of Internal Thread and Truncation of Internal Thread $\frac{H}{4}$ 0.2165064 <i>P</i> | Dedendum of Internal Thread and Addendum External Thread $\frac{3H}{8}$ 0.3247595 <i>P</i> | Difference ^a 0.4330127 <i>P</i> | Height of Internal Thread and Depth of Thread Engagement $\frac{5H}{8}$ 0.5412659 <i>P</i> | Difference ^b 0.711325 <i>H</i> 0.6160254 <i>P</i> | Twice the External Thread Addendum $\frac{3H}{4}$ 0.649519/ <i>P</i> | Difference ^c 0.7938566 <i>P</i> | Height of Sharp V-Thread $\frac{H}{12}$ 0.8660254 <i>P</i> | Double Height of Internal Thread $\frac{5H}{4}$ 1.082518 <i>P</i> |
|-------------------|--|---|---|---|---|--|--|---|--|---|
| 0.2 | 0.02165 | 0.04330 | 0.06495 | 0.08660 | 0.10825 | 0.12321 | 0.12990 | 0.15877 | 0.17321 | 0.21651 |
| 0.25 | 0.02706 | 0.05413 | 0.08119 | 0.10825 | 0.13532 | 0.15401 | 0.16238 | 0.19846 | 0.21651 | 0.27063 |
| 0.3 | 0.03248 | 0.06495 | 0.09743 | 0.12990 | 0.16238 | 0.18481 | 0.19486 | 0.23816 | 0.25981 | 0.32476 |
| 0.35 | 0.03789 | 0.07578 | 0.11367 | 0.15155 | 0.18944 | 0.21561 | 0.22733 | 0.27785 | 0.30311 | 0.37889 |
| 0.4 | 0.04330 | 0.08660 | 0.12990 | 0.17321 | 0.21651 | 0.24541 | 0.25981 | 0.31754 | 0.34641 | 0.43301 |
| 0.45 | 0.04871 | 0.09743 | 0.14614 | 0.19486 | 0.24357 | 0.27721 | 0.29228 | 0.35724 | 0.38971 | 0.48714 |
| 0.5 | 0.05413 | 0.10825 | 0.16238 | 0.21651 | 0.27063 | 0.30801 | 0.32476 | 0.39693 | 0.43301 | 0.54127 |
| 0.6 | 0.06495 | 0.12990 | 0.19486 | 0.25981 | 0.32476 | 0.36962 | 0.38971 | 0.47631 | 0.51962 | 0.64952 |
| 0.7 | 0.07578 | 0.15155 | 0.22733 | 0.30311 | 0.37889 | 0.43122 | 0.45466 | 0.55570 | 0.60622 | 0.75777 |
| 0.75 | 0.08119 | 0.16238 | 0.24357 | 0.32476 | 0.40595 | 0.46202 | 0.48714 | 0.59539 | 0.64952 | 0.81190 |
| 0.8 | 0.08660 | 0.17321 | 0.25981 | 0.34641 | 0.43301 | 0.49282 | 0.51962 | 0.63509 | 0.69282 | 0.86603 |
| 1 | 0.10825 | 0.21651 | 0.32476 | 0.43301 | 0.54127 | 0.61603 | 0.64952 | 0.79386 | 0.86603 | 1.08253 |
| 1.25 | 0.13532 | 0.27063 | 0.40595 | 0.54127 | 0.67658 | 0.77003 | 0.81190 | 0.99232 | 1.08253 | 1.35316 |
| 1.5 | 0.16238 | 0.32476 | 0.48714 | 0.64952 | 0.81190 | 0.92404 | 0.97428 | 1.19078 | 1.29904 | 1.62380 |
| 1.75 | 0.18944 | 0.37889 | 0.56833 | 0.75777 | 0.94722 | 1.07804 | 1.13666 | 1.38925 | 1.51554 | 1.89443 |
| 2 | 0.21651 | 0.43301 | 0.64952 | 0.86603 | 1.08253 | 1.23205 | 1.29904 | 1.58771 | 1.73205 | 2.16506 |
| 2.5 | 0.27063 | 0.54127 | 0.81190 | 1.08253 | 1.35316 | 1.54006 | 1.62380 | 1.98464 | 2.16506 | 2.70633 |
| 3 | 0.32476 | 0.64652 | 0.97428 | 1.29904 | 1.62380 | 1.84808 | 1.94856 | 2.38157 | 2.59808 | 3.24760 |
| 3.5 | 0.37889 | 0.75777 | 1.13666 | 1.51554 | 1.89443 | 2.15609 | 2.27332 | 2.77850 | 3.03109 | 3.78886 |
| 4 | 0.43301 | 0.86603 | 1.29904 | 1.73205 | 2.16506 | 2.46410 | 2.59808 | 3.17543 | 3.46410 | 4.33013 |
| 4.5 | 0.48714 | 0.97428 | 1.46142 | 1.94856 | 2.43570 | 2.77211 | 2.92284 | 3.57235 | 3.89711 | 4.87139 |
| 5 | 0.54127 | 1.08253 | 1.62380 | 2.16506 | 2.70633 | 3.08013 | 3.24760 | 3.96928 | 4.33013 | 5.41266 |
| 5.5 | 0.59539 | 1.19079 | 1.78618 | 2.38157 | 2.97696 | 3.38814 | 3.57236 | 4.36621 | 4.76314 | 5.95392 |
| 6 | 0.64952 | 1.29904 | 1.94856 | 2.59808 | 3.24760 | 3.69615 | 3.89711 | 4.76314 | 5.19615 | 6.49519 |
| 8 | 0.86603 | 1.73205 | 2.59808 | 3.46410 | 4.33013 | 4.92820 | 5.19615 | 6.35085 | 6.92820 | 8.66025 |

^aDifference between max theoretical pitch diameter and max minor diameter of external thread and between min theoretical pitch diameter and min minor diameter of internal thread.

^bDifference between min theoretical pitch diameter and min design minor diameter of external thread for 0.125*P* root radius.

^cDifference between max major diameter and max theoretical pitch diameter of internal thread.

All dimensions are in millimeters.

Table 11. Internal Metric Thread—M Profile Limiting Dimensions, ANSI/ASME B1.13M-2001

| Basic Thread Designation | Toler. Class | Minor Diameter D_1 | | Pitch Diameter D_2 | | | Major Diameter D | |
|--------------------------|--------------|----------------------|--------|----------------------|--------|-------|--------------------|------------------|
| | | Min | Max | Min | Max | Tol | Min | Max ^a |
| M1.6 × 0.35 | 6H | 1.221 | 1.321 | 1.373 | 1.458 | 0.085 | 1.600 | 1.736 |
| M2 × 0.4 | 6H | 1.567 | 1.679 | 1.740 | 1.830 | 0.090 | 2.000 | 2.148 |
| M2.5 × 0.45 | 6H | 2.013 | 2.138 | 2.208 | 2.303 | 0.095 | 2.500 | 2.660 |
| M3 × 0.5 | 6H | 2.459 | 2.599 | 2.675 | 2.775 | 0.100 | 3.000 | 3.172 |
| M3.5 × 0.6 | 6H | 2.850 | 3.010 | 3.110 | 3.222 | 0.112 | 3.500 | 3.698 |
| M4 × 0.7 | 6H | 3.242 | 3.422 | 3.545 | 3.663 | 0.118 | 4.000 | 4.219 |
| M5 × 0.8 | 6H | 4.134 | 4.334 | 4.480 | 4.605 | 0.125 | 5.000 | 5.240 |
| M6 × 1 | 6H | 4.917 | 5.153 | 5.350 | 5.500 | 0.150 | 6.000 | 6.294 |
| M8 × 1.25 | 6H | 6.647 | 6.912 | 7.188 | 7.348 | 0.160 | 8.000 | 8.340 |
| M8 × 1 | 6H | 6.917 | 7.153 | 7.350 | 7.500 | 0.150 | 8.000 | 8.294 |
| M10 × 0.75 | 6H | 9.188 | 9.378 | 9.513 | 9.645 | 0.132 | 10.000 | 10.240 |
| M10 × 1 | 6H | 8.917 | 9.153 | 9.350 | 9.500 | 0.150 | 10.000 | 10.294 |
| M10 × 1.5 | 6H | 8.376 | 8.676 | 9.026 | 9.206 | 0.180 | 10.000 | 10.397 |
| M10 × 1.25 | 6H | 8.647 | 8.912 | 9.188 | 9.348 | 0.160 | 10.000 | 10.340 |
| M12 × 1.75 | 6H | 10.106 | 10.441 | 10.863 | 11.063 | 0.200 | 12.000 | 12.452 |
| M12 × 1.5 | 6H | 10.376 | 10.676 | 11.026 | 11.216 | 0.190 | 12.000 | 12.407 |
| M12 × 1.25 | 6H | 10.647 | 10.912 | 11.188 | 11.368 | 0.180 | 12.000 | 12.360 |
| M12 × 1 | 6H | 10.917 | 11.153 | 11.350 | 11.510 | 0.160 | 12.000 | 12.304 |
| M14 × 2 | 6H | 11.835 | 12.210 | 12.701 | 12.913 | 0.212 | 14.000 | 14.501 |
| M14 × 1.5 | 6H | 12.376 | 12.676 | 13.026 | 13.216 | 0.190 | 14.000 | 14.407 |
| M15 × 1 | 6H | 13.917 | 14.153 | 14.350 | 14.510 | 0.160 | 15.000 | 15.304 |
| M16 × 2 | 6H | 13.835 | 14.210 | 14.701 | 14.913 | 0.212 | 16.000 | 16.501 |
| M16 × 1.5 | 6H | 14.376 | 14.676 | 15.026 | 15.216 | 0.190 | 16.000 | 16.407 |
| M17 × 1 | 6H | 15.917 | 16.153 | 16.350 | 16.510 | 0.160 | 17.000 | 17.304 |
| M18 × 1.5 | 6H | 16.376 | 16.676 | 17.026 | 17.216 | 0.190 | 18.000 | 18.407 |
| M20 × 2.5 | 6H | 17.294 | 17.744 | 18.376 | 18.600 | 0.224 | 20.000 | 20.585 |
| M20 × 1.5 | 6H | 18.376 | 18.676 | 19.026 | 19.216 | 0.190 | 20.000 | 20.407 |
| M20 × 1 | 6H | 18.917 | 19.153 | 19.350 | 19.510 | 0.160 | 20.000 | 20.304 |
| M22 × 2.5 | 6H | 19.294 | 19.744 | 20.376 | 20.600 | 0.224 | 22.000 | 22.585 |
| M22 × 1.5 | 6H | 20.376 | 20.676 | 21.026 | 21.216 | 0.190 | 22.000 | 22.407 |
| M24 × 3 | 6H | 20.752 | 21.252 | 22.051 | 22.316 | 0.265 | 24.000 | 24.698 |
| M24 × 2 | 6H | 21.835 | 22.210 | 22.701 | 22.925 | 0.224 | 24.000 | 24.513 |
| M25 × 1.5 | 6H | 23.376 | 23.676 | 24.026 | 24.226 | 0.200 | 25.000 | 25.417 |
| M27 × 3 | 6H | 23.752 | 24.252 | 25.051 | 25.316 | 0.265 | 27.000 | 27.698 |
| M27 × 2 | 6H | 24.835 | 25.210 | 25.701 | 25.925 | 0.224 | 27.000 | 27.513 |
| M30 × 3.5 | 6H | 26.211 | 26.771 | 27.727 | 28.007 | 0.280 | 30.000 | 30.786 |
| M30 × 2 | 6H | 27.835 | 28.210 | 28.701 | 28.925 | 0.224 | 30.000 | 30.513 |
| M30 × 1.5 | 6H | 28.376 | 28.676 | 29.026 | 29.226 | 0.200 | 30.000 | 30.417 |
| M33 × 2 | 6H | 30.835 | 31.210 | 31.701 | 31.925 | 0.224 | 33.000 | 33.513 |
| M35 × 1.5 | 6H | 33.376 | 33.676 | 34.026 | 34.226 | 0.200 | 35.000 | 35.417 |
| M36 × 4 | 6H | 31.670 | 32.270 | 33.402 | 33.702 | 0.300 | 36.000 | 36.877 |
| M36 × 2 | 6H | 33.835 | 34.210 | 34.701 | 34.925 | 0.224 | 36.000 | 36.513 |

**Table 11. (Continued) Internal Metric Thread—M Profile
Limiting Dimensions, ANSI/ASME B1.13M-2001**

| Basic Thread Designation | Toler. Class | Minor Diameter D_1 | | Pitch Diameter D_2 | | | Major Diameter D | |
|--------------------------|--------------|----------------------|---------|----------------------|---------|-------|--------------------|------------------|
| | | Min | Max | Min | Max | Tol | Min | Max ^a |
| M39 × 2 | 6H | 36.835 | 37.210 | 37.701 | 37.925 | 0.224 | 39.000 | 39.513 |
| M40 × 1.5 | 6H | 38.376 | 38.676 | 39.026 | 39.226 | 0.200 | 40.000 | 40.417 |
| M42 × 4.5 | 6H | 37.129 | 37.799 | 39.077 | 39.392 | 0.315 | 42.000 | 42.964 |
| M42 × 2 | 6H | 39.835 | 40.210 | 40.701 | 40.925 | 0.224 | 42.000 | 42.513 |
| M45 × 1.5 | 6H | 43.376 | 43.676 | 44.026 | 44.226 | 0.200 | 45.000 | 45.417 |
| M48 × 5 | 6H | 42.587 | 43.297 | 44.752 | 45.087 | 0.335 | 48.000 | 49.056 |
| M48 × 2 | 6H | 45.835 | 46.210 | 46.701 | 46.937 | 0.236 | 48.000 | 48.525 |
| M50 × 1.5 | 6H | 48.376 | 48.676 | 49.026 | 49.238 | 0.212 | 50.000 | 50.429 |
| M55 × 1.5 | 6H | 53.376 | 53.676 | 54.026 | 54.238 | 0.212 | 55.000 | 55.429 |
| M56 × 5.5 | 6H | 50.046 | 50.796 | 52.428 | 52.783 | 0.355 | 56.000 | 57.149 |
| M56 × 2 | 6H | 53.835 | 54.210 | 54.701 | 54.937 | 0.236 | 56.000 | 56.525 |
| M60 × 1.5 | 6H | 58.376 | 58.676 | 59.026 | 59.238 | 0.212 | 60.000 | 60.429 |
| M64 × 6 | 6H | 57.505 | 58.305 | 60.103 | 60.478 | 0.375 | 64.000 | 65.241 |
| M64 × 2 | 6H | 61.835 | 62.210 | 62.701 | 62.937 | 0.236 | 64.000 | 64.525 |
| M65 × 1.5 | 6H | 63.376 | 63.676 | 64.026 | 64.238 | 0.212 | 65.000 | 65.429 |
| M70 × 1.5 | 6H | 68.376 | 68.676 | 69.026 | 69.238 | 0.212 | 70.000 | 70.429 |
| M72 × 6 | 6H | 65.505 | 66.305 | 68.103 | 68.478 | 0.375 | 72.000 | 73.241 |
| M72 × 2 | 6H | 69.835 | 70.210 | 70.701 | 70.937 | 0.236 | 72.000 | 72.525 |
| M75 × 1.5 | 6H | 73.376 | 73.676 | 74.026 | 74.238 | 0.212 | 75.000 | 75.429 |
| M80 × 6 | 6H | 73.505 | 74.305 | 76.103 | 76.478 | 0.375 | 80.000 | 81.241 |
| M80 × 2 | 6H | 77.835 | 78.210 | 78.701 | 78.937 | 0.236 | 80.000 | 80.525 |
| M80 × 1.5 | 6H | 78.376 | 78.676 | 79.026 | 79.238 | 0.212 | 80.000 | 80.429 |
| M85 × 2 | 6H | 82.835 | 83.210 | 83.701 | 83.937 | 0.236 | 85.000 | 85.525 |
| M90 × 6 | 6H | 83.505 | 84.305 | 86.103 | 86.478 | 0.375 | 90.000 | 91.241 |
| M90 × 2 | 6H | 87.835 | 88.210 | 88.701 | 88.937 | 0.236 | 90.000 | 90.525 |
| M95 × 2 | 6H | 92.835 | 93.210 | 93.701 | 93.951 | 0.250 | 95.000 | 95.539 |
| M100 × 6 | 6H | 93.505 | 94.305 | 96.103 | 96.503 | 0.400 | 100.000 | 101.266 |
| M100 × 2 | 6H | 97.835 | 98.210 | 98.701 | 98.951 | 0.250 | 100.000 | 100.539 |
| M105 × 2 | 6H | 102.835 | 103.210 | 103.701 | 103.951 | 0.250 | 105.000 | 105.539 |
| M110 × 2 | 6H | 107.835 | 108.210 | 108.701 | 108.951 | 0.250 | 110.000 | 110.539 |
| M120 × 2 | 6H | 117.835 | 118.210 | 118.701 | 118.951 | 0.250 | 120.000 | 120.539 |
| M130 × 2 | 6H | 127.835 | 128.210 | 128.701 | 128.951 | 0.250 | 130.000 | 130.539 |
| M140 × 2 | 6H | 137.835 | 138.210 | 138.701 | 138.951 | 0.250 | 140.000 | 140.539 |
| M150 × 2 | 6H | 147.835 | 148.210 | 148.701 | 148.951 | 0.250 | 150.000 | 150.539 |
| M160 × 3 | 6H | 156.752 | 157.252 | 158.051 | 158.351 | 0.300 | 160.000 | 160.733 |
| M170 × 3 | 6H | 166.752 | 167.252 | 168.051 | 168.351 | 0.300 | 170.000 | 170.733 |
| M180 × 3 | 6H | 176.752 | 177.252 | 178.051 | 178.351 | 0.300 | 180.000 | 180.733 |
| M190 × 3 | 6H | 186.752 | 187.252 | 188.051 | 188.386 | 0.335 | 190.000 | 190.768 |
| M200 × 3 | 6H | 196.752 | 197.252 | 198.051 | 198.386 | 0.335 | 200.000 | 200.768 |

^aThis reference dimension is used in design of tools, etc., and is not normally specified. Generally, major diameter acceptance is based upon maximum material condition gaging.

All dimensions are in millimeters.

Table 12. External Metric Thread—M Profile Limiting Dimensions ANSI/ASME B1.13M-2001

| Basic Thread Designation | Tol. Class | Allowance ^a <i>es</i> | Major Diameter ^b <i>d</i> | | Pitch Diameter ^{b c} <i>d</i> ₂ | | | Minor Dia. ^b <i>d</i> ₁ | Minor Dia. ^d <i>d</i> ₃ |
|--------------------------|------------|-------------------------------------|---|--------|--|--------|-------|--|--|
| | | | Max. | Min. | Max. | Min. | Tol. | | |
| M1.6 × 0.35 | 6g | 0.019 | 1.581 | 1.496 | 1.354 | 1.291 | 0.063 | 1.202 | 1.075 |
| M1.6 × 0.35 | 6h | 0.000 | 1.600 | 1.515 | 1.373 | 1.310 | 0.063 | 1.221 | 1.094 |
| M1.6 × 0.35 | 4g6g | 0.019 | 1.581 | 1.496 | 1.354 | 1.314 | 0.040 | 1.202 | 1.098 |
| M2 × 0.4 | 6g | 0.019 | 1.981 | 1.886 | 1.721 | 1.654 | 0.067 | 1.548 | 1.408 |
| M2 × 0.4 | 6h | 0.000 | 2.000 | 1.905 | 1.740 | 1.673 | 0.067 | 1.567 | 1.427 |
| M2 × 0.4 | 4g6g | 0.019 | 1.981 | 1.886 | 1.721 | 1.679 | 0.042 | 1.548 | 1.433 |
| M2.5 × 0.45 | 6g | 0.020 | 2.480 | 2.380 | 2.188 | 2.117 | 0.071 | 1.993 | 1.840 |
| M2.5 × 0.45 | 6h | 0.000 | 2.500 ^e | 2.400 | 2.208 | 2.137 | 0.071 | 2.013 | 1.860 |
| M2.5 × 0.45 | 4g6g | 0.020 | 2.480 | 2.380 | 2.188 | 2.143 | 0.045 | 1.993 | 1.866 |
| M3 × 0.5 | 6g | 0.020 | 2.980 | 2.874 | 2.655 | 2.580 | 0.075 | 2.438 | 2.272 |
| M3 × 0.5 | 6h | 0.000 | 3.000 | 2.894 | 2.675 | 2.600 | 0.075 | 2.458 | 2.292 |
| M3 × 0.5 | 4g6g | 0.020 | 2.980 | 2.874 | 2.655 | 2.607 | 0.048 | 2.438 | 2.299 |
| M3.5 × 0.6 | 6g | 0.021 | 3.479 | 3.354 | 3.089 | 3.004 | 0.085 | 2.829 | 2.634 |
| M3.5 × 0.6 | 6h | 0.000 | 3.500 | 3.375 | 3.110 | 3.025 | 0.085 | 2.850 | 2.655 |
| M3.5 × 0.6 | 4g6g | 0.021 | 3.479 | 3.354 | 3.089 | 3.036 | 0.053 | 2.829 | 2.666 |
| M4 × 0.7 | 6g | 0.022 | 3.978 | 3.838 | 3.523 | 3.433 | 0.090 | 3.220 | 3.002 |
| M4 × 0.7 | 6h | 0.000 | 4.000 | 3.860 | 3.545 | 3.455 | 0.090 | 3.242 | 3.024 |
| M4 × 0.7 | 4g6g | 0.022 | 3.978 | 3.838 | 3.523 | 3.467 | 0.056 | 3.220 | 3.036 |
| M5 × 0.8 | 6g | 0.024 | 4.976 | 4.826 | 4.456 | 4.361 | 0.095 | 4.110 | 3.868 |
| M5 × 0.8 | 6h | 0.000 | 5.000 | 4.850 | 4.480 | 4.385 | 0.095 | 4.134 | 3.892 |
| M5 × 0.8 | 4g6g | 0.024 | 4.976 | 4.826 | 4.456 | 4.396 | 0.060 | 4.110 | 3.903 |
| M6 × 1 | 6g | 0.026 | 5.974 | 5.794 | 5.324 | 5.212 | 0.112 | 4.891 | 4.596 |
| M6 × 1 | 6h | 0.000 | 6.000 | 5.820 | 5.350 | 5.238 | 0.112 | 4.917 | 4.622 |
| M6 × 1 | 4g6g | 0.026 | 5.974 | 5.794 | 5.324 | 5.253 | 0.071 | 4.891 | 4.637 |
| MS × 1.25 | 6g | 0.028 | 7.972 | 7.760 | 7.160 | 7.042 | 0.118 | 6.619 | 6.272 |
| M8 × 1.25 | 6h | 0.000 | 8.000 | 7.788 | 7.188 | 7.070 | 0.118 | 6.647 | 6.300 |
| M8 × 1.25 | 4g6g | 0.028 | 7.972 | 7.760 | 7.160 | 7.085 | 0.075 | 6.619 | 6.315 |
| M8 × 1 | 6g | 0.026 | 7.974 | 7.794 | 7.324 | 7.212 | 0.112 | 6.891 | 6.596 |
| M8 × 1 | 6h | 0.000 | 8.000 | 7.820 | 7.350 | 7.238 | 0.112 | 6.917 | 6.622 |
| M8 × 1 | 4g6g | 0.026 | 7.974 | 7.794 | 7.324 | 7.253 | 0.071 | 6.891 | 6.637 |
| M10 × 1.5 | 6g | 0.032 | 9.968 | 9.732 | 8.994 | 8.862 | 0.132 | 8.344 | 7.938 |
| M10 × 1.5 | 6h | 0.000 | 10.000 | 9.764 | 9.026 | 8.894 | 0.132 | 8.376 | 7.970 |
| M10 × 1.5 | 4g6g | 0.032 | 9.968 | 9.732 | 8.994 | 8.909 | 0.085 | 8.344 | 7.985 |
| M10 × 1.25 | 6g | 0.028 | 9.972 | 9.760 | 9.160 | 9.042 | 0.118 | 8.619 | 8.272 |
| M10 × 1.25 | 6h | 0.000 | 10.000 | 9.788 | 9.188 | 9.070 | 0.118 | 8.647 | 8.300 |
| M10 × 1.25 | 4g6g | 0.028 | 9.972 | 9.760 | 9.160 | 9.085 | 0.075 | 8.619 | 8.315 |
| M10 × 1 | 6g | 0.026 | 9.974 | 9.794 | 9.324 | 9.212 | 0.112 | 8.891 | 8.596 |
| M10 × 1 | 6h | 0.000 | 10.000 | 9.820 | 9.350 | 9.238 | 0.112 | 8.917 | 8.622 |
| M10 × 1 | 4g6g | 0.026 | 9.974 | 9.794 | 9.324 | 9.253 | 0.071 | 8.891 | 8.637 |
| M10 × 0.75 | 6g | 0.022 | 9.978 | 9.838 | 9.491 | 9.391 | 0.100 | 9.166 | 8.929 |
| M10 × 0.75 | 6h | 0.000 | 10.000 | 9.860 | 9.513 | 9.413 | 0.100 | 9.188 | 8.951 |
| M10 × 0.75 | 4g6g | 0.022 | 9.978 | 9.838 | 9.491 | 9.428 | 0.063 | 9.166 | 8.966 |
| M12 × 1.75 | 6g | 0.034 | 11.966 | 11.701 | 10.829 | 10.679 | 0.150 | 10.071 | 9.601 |
| M12 × 1.75 | 6h | 0.000 | 12.000 | 11.735 | 10.863 | 10.713 | 0.150 | 10.105 | 9.635 |
| M12 × 1.75 | 4g6g | 0.034 | 11.966 | 11.701 | 10.829 | 10.734 | 0.095 | 10.071 | 9.656 |
| M12 × 1.5 | 6g | 0.032 | 11.968 | 11.732 | 10.994 | 10.854 | 0.140 | 10.344 | 9.930 |
| M12 × 1.5 | 6h | 0.000 | 12.000 | 11.764 | 11.026 | 10.886 | 0.140 | 10.376 | 9.962 |
| M12 × 1.5 | 4g6g | 0.032 | 11.968 | 11.732 | 10.994 | 10.904 | 0.090 | 10.344 | 9.980 |
| M12 × 1.25 | 6g | 0.028 | 11.972 | 11.760 | 11.160 | 11.028 | 0.132 | 10.619 | 10.258 |
| M12 × 1.25 | 6h | 0.000 | 12.000 | 11.788 | 11.188 | 11.056 | 0.132 | 10.647 | 10.286 |
| M12 × 1.25 | 4g6g | 0.028 | 11.972 | 11.760 | 11.160 | 11.075 | 0.085 | 10.619 | 10.305 |
| M12 × 1 | 6g | 0.026 | 11.974 | 11.794 | 11.324 | 11.206 | 0.118 | 10.891 | 10.590 |
| M12 × 1 | 6h | 0.000 | 12.000 | 11.820 | 11.350 | 11.232 | 0.118 | 10.917 | 10.616 |
| M12 × 1 | 4g6g | 0.026 | 11.974 | 11.794 | 11.324 | 11.249 | 0.075 | 10.891 | 10.633 |
| M14 × 2 | 6g | 0.038 | 13.962 | 13.682 | 12.663 | 12.503 | 0.160 | 11.797 | 11.271 |
| M14 × 2 | 6h | 0.000 | 14.000 | 13.720 | 12.701 | 12.541 | 0.160 | 11.835 | 11.309 |
| M14 × 2 | 4g6g | 0.038 | 13.962 | 13.682 | 12.663 | 12.563 | 0.100 | 11.797 | 11.331 |
| M14 × 1.5 | 6g | 0.032 | 13.968 | 13.732 | 12.994 | 12.854 | 0.140 | 12.344 | 11.930 |
| M14 × 1.5 | 6h | 0.000 | 14.000 | 13.764 | 13.026 | 12.886 | 0.140 | 12.376 | 11.962 |
| M14 × 1.5 | 4g6g | 0.032 | 13.968 | 13.732 | 12.994 | 12.904 | 0.090 | 12.344 | 11.980 |
| M15 × 1 | 6g | 0.026 | 14.974 | 14.794 | 14.324 | 14.206 | 0.118 | 13.891 | 13.590 |
| M15 × 1 | 6h | 0.000 | 15.000 | 14.820 | 14.350 | 14.232 | 0.118 | 13.917 | 13.616 |
| M15 × 1 | 4g6g | 0.026 | 14.974 | 14.794 | 14.324 | 14.249 | 0.075 | 13.891 | 13.633 |

**Table 12. (Continued) External Metric Thread—M Profile
Limiting Dimensions ANSI/ASME B1.13M-2001**

| Basic Thread Designation | Tol. Class | Allowance ^a <i>es</i> | Major Diameter ^b <i>d</i> | | Pitch Diameter ^{b c} <i>d</i> ₂ | | | Minor Dia. ^b <i>d</i> ₁ | Minor Dia. ^d <i>d</i> ₃ |
|--------------------------|------------|-------------------------------------|---|--------|--|--------|-------|--|--|
| | | | Max. | Min. | Max. | Min. | Tol. | | |
| M16 × 2 | 6g | 0.038 | 15.962 | 15.682 | 14.663 | 14.503 | 0.160 | 13.797 | 13.271 |
| M16 × 2 | 6h | 0.000 | 16.000 | 15.720 | 14.701 | 14.541 | 0.160 | 13.835 | 13.309 |
| M16 × 2 | 4g6g | 0.038 | 15.962 | 15.682 | 14.663 | 14.563 | 0.100 | 13.797 | 13.331 |
| M16 × 1.5 | 6g | 0.032 | 15.968 | 15.732 | 14.994 | 14.854 | 0.140 | 14.344 | 13.930 |
| M16 × 1.5 | 6h | 0.000 | 16.000 | 15.764 | 15.026 | 14.886 | 0.140 | 14.376 | 13.962 |
| M16 × 1.5 | 4g6g | 0.032 | 15.968 | 15.732 | 14.994 | 14.904 | 0.090 | 14.344 | 13.980 |
| M17 × 1 | 6g | 0.026 | 16.974 | 16.794 | 16.324 | 16.206 | 0.118 | 15.891 | 15.590 |
| M17 × 1 | 6h | 0.000 | 17.000 | 16.820 | 16.350 | 16.232 | 0.118 | 15.917 | 15.616 |
| M17 × 1 | 4g6g | 0.026 | 16.974 | 16.794 | 16.324 | 16.249 | 0.075 | 15.891 | 15.633 |
| M18 × 1.5 | 6g | 0.032 | 17.968 | 17.732 | 16.994 | 16.854 | 0.140 | 16.344 | 15.930 |
| M18 × 1.5 | 6h | 0.000 | 18.000 | 17.764 | 17.026 | 16.886 | 0.140 | 16.376 | 15.962 |
| M18 × 1.5 | 4g6g | 0.032 | 17.968 | 17.732 | 16.994 | 16.904 | 0.090 | 16.344 | 15.980 |
| M20 × 2.5 | 6g | 0.042 | 19.958 | 19.623 | 18.334 | 18.164 | 0.170 | 17.251 | 16.624 |
| M20 × 2.5 | 6h | 0.000 | 20.000 | 19.665 | 18.376 | 18.206 | 0.170 | 17.293 | 16.666 |
| M20 × 2.5 | 4g6g | 0.042 | 19.958 | 19.623 | 18.334 | 18.228 | 0.106 | 17.251 | 16.688 |
| M20 × 1.5 | 6g | 0.032 | 19.968 | 19.732 | 18.994 | 18.854 | 0.140 | 18.344 | 17.930 |
| M20 × 1.5 | 6h | 0.000 | 20.000 | 19.764 | 19.026 | 18.886 | 0.140 | 18.376 | 17.962 |
| M20 × 1.5 | 4g6g | 0.032 | 19.968 | 19.732 | 18.994 | 18.904 | 0.090 | 18.344 | 17.980 |
| M20 × 1 | 6g | 0.026 | 19.974 | 19.794 | 19.324 | 19.206 | 0.118 | 18.891 | 18.590 |
| M20 × 1 | 6h | 0.000 | 20.000 | 19.820 | 19.350 | 19.232 | 0.118 | 18.917 | 18.616 |
| M20 × 1 | 4g6g | 0.026 | 19.974 | 19.794 | 19.324 | 19.249 | 0.075 | 18.891 | 18.633 |
| M22 × 2.5 | 6g | 0.042 | 21.958 | 21.623 | 20.334 | 20.164 | 0.170 | 19.251 | 18.624 |
| M22 × 2.5 | 6h | 0.000 | 22.000 | 21.665 | 20.376 | 20.206 | 0.170 | 19.293 | 18.666 |
| M22 × 1.5 | 6g | 0.032 | 21.968 | 21.732 | 20.994 | 20.854 | 0.140 | 20.344 | 19.930 |
| M22 × 1.5 | 6h | 0.000 | 22.000 | 21.764 | 21.026 | 20.886 | 0.140 | 20.376 | 19.962 |
| M22 × 1.5 | 4g6g | 0.032 | 21.968' | 21.732 | 20.994 | 20.904 | 0.090 | 20.344 | 19.980 |
| M24 × 3 | 6g | 0.048 | 23.952 | 23.577 | 22.003 | 21.803 | 0.200 | 20.704 | 19.955 |
| M24 × 3 | 6h | 0.000 | 24.000 | 23.625 | 22.051 | 21.851 | 0.200 | 20.752 | 20.003 |
| M24 × 3 | 4g6g | 0.048 | 23.952 | 23.577 | 22.003 | 21.878 | 0.125 | 20.704 | 20.030 |
| M24 × 2 | 6g | 0.038 | 23.962 | 23.682 | 22.663 | 22.493 | 0.170 | 21.797 | 21.261 |
| M24 × 2 | 6h | 0.000 | 24.000 | 23.720 | 22.701 | 22.531 | 0.170 | 21.835 | 21.299 |
| M24 × 2 | 4g6g | 0.038 | 23.962 | 23.682 | 22.663 | 22.557 | 0.106 | 21.797 | 21.325 |
| M25 × 1.5 | 6g | 0.032 | 24.968 | 24.732 | 23.994 | 23.844 | 0.150 | 23.344 | 22.920 |
| M25 × 1.5 | 6h | 0.000 | 25.000 | 24.764 | 24.026 | 23.876 | 0.150 | 23.376 | 22.952 |
| M25 × 1.5 | 4g6g | 0.032 | 24.968 | 24.732 | 23.994 | 23.899 | 0.095 | 23.344 | 22.975 |
| M27 × 3 | 6g | 0.048 | 26.952 | 26.577 | 25.003 | 24.803 | 0.200 | 23.704 | 22.955 |
| M27 × 3 | 6h | 0.000 | 27.000 | 26.625 | 25.051 | 24.851 | 0.200 | 23.752 | 23.003 |
| M27 × 2 | 6g | 0.038 | 26.962 | 26.682 | 25.663 | 25.493 | 0.170 | 24.797 | 24.261 |
| M27 × 2 | 6h | 0.000 | 27.000 | 26.720 | 25.701 | 25.531 | 0.170 | 24.835 | 24.299 |
| M27 × 2 | 4g6g | 0.038 | 26.962 | 26.682 | 25.663 | 25.557 | 0.106 | 24.797 | 24.325 |
| M30 × 3.5 | 6g | 0.053 | 29.947 | 29.522 | 27.674 | 27.462 | 0.212 | 26.158 | 25.306 |
| M30 × 3.5 | 6h | 0.000 | 30.000 | 29.575 | 27.727 | 27.515 | 0.212 | 26.211 | 25.359 |
| M30 × 3.5 | 4g6g | 0.053 | 29.947 | 29.522 | 27.674 | 27.542 | 0.132 | 26.158 | 25.386 |
| M30 × 2 | 6g | 0.038 | 29.962 | 29.682 | 28.663 | 28.493 | 0.170 | 27.797 | 27.261 |
| M30 × 2 | 6h | 0.000 | 30.000 | 29.720 | 28.701 | 28.531 | 0.170 | 27.835 | 27.299 |
| M30 × 2 | 4g6g | 0.038 | 29.962 | 29.682 | 28.663 | 28.557 | 0.106 | 27.797 | 27.325 |
| M30 × 1.5 | 6g | 0.032 | 29.968 | 29.732 | 28.994 | 28.844 | 0.150 | 28.344 | 27.920 |
| M30 × 1.5 | 6h | 0.000 | 30.000 | 29.764 | 29.026 | 28.876 | 0.150 | 28.376 | 27.952 |
| M30 × 1.5 | 4g6g | 0.032 | 29.968 | 29.732 | 28.994 | 28.899 | 0.095 | 28.344 | 27.975 |
| M33 × 2 | 6g | 0.038 | 32.962 | 32.682 | 31.663 | 31.493 | 0.170 | 30.797 | 30.261 |
| M33 × 2 | 6h | 0.000 | 33.000 | 32.720 | 31.701 | 31.531 | 0.170 | 30.835 | 30.299 |
| M33 × 2 | 4g6g | 0.038 | 32.962 | 32.682 | 31.663 | 31.557 | 0.106 | 30.797 | 30.325 |
| M35 × 1.5 | 6g | 0.032 | 34.968 | 34.732 | 33.994 | 33.844 | 0.150 | 33.344 | 32.920 |
| M35 × 1.5 | 6h | 0.000 | 35.000 | 34.764 | 34.026 | 33.876 | 0.150 | 33.376 | 32.952 |
| M36 × 4 | 6g | 0.060 | 35.940 | 35.465 | 33.342 | 33.118 | 0.224 | 31.610 | 30.654 |
| M36 × 4 | 6h | 0.000 | 36.000 | 35.525 | 33.402 | 33.178 | 0.224 | 31.670 | 30.714 |
| M36 × 4 | 4g6g | 0.060 | 35.940 | 35.465 | 33.342 | 33.202 | 0.140 | 31.610 | 30.738 |
| M36 × 2 | 6g | 0.038 | 35.962 | 35.682 | 34.663 | 34.493 | 0.170 | 33.797 | 33.261 |
| M36 × 2 | 6h | 0.000 | 36.000 | 35.720 | 34.701 | 34.531 | 0.170 | 33.835 | 33.299 |
| M36 × 2 | 4g6g | 0.038 | 35.962 | 35.682 | 34.663 | 34.557 | 0.106 | 33.797 | 33.325 |
| M39 × 2 | 6g | 0.038 | 38.962 | 38.682 | 37.663 | 37.493 | 0.170 | 36.797 | 36.261 |
| M39 × 2 | 6h | 0.000 | 39.000 | 38.720 | 37.701 | 37.531 | 0.170 | 36.835 | 36.299 |
| M39 × 2 | 4g6g | 0.038 | 38.962 | 38.682 | 37.663 | 37.557 | 0.106 | 36.797 | 36.325 |
| M40 × 1.5 | 6g | 0.032 | 39.968 | 39.732 | 38.994 | 38.844 | 0.150 | 38.344 | 37.920 |

Table 12. (Continued) External Metric Thread—M Profile Limiting Dimensions ANSI/ASME B1.13M-2001

| Basic Thread Designation | Tol. Class | Allowance ^a <i>es</i> | Major Diameter ^b <i>d</i> | | Pitch Diameter ^{b c} <i>d</i> ₂ | | | Minor Dia. ^b <i>d</i> ₁ | Minor Dia. ^d <i>d</i> ₃ |
|--------------------------|------------|-------------------------------------|---|--------|--|--------|-------|--|--|
| | | | Max. | Min. | Max. | Min. | Tol. | | |
| M40 × 1.5 | 6h | 0.000 | 40.000 | 39.764 | 39.026 | 38.876 | 0.150 | 38.376 | 37.952 |
| M40 × 1.5 | 4g6g | 0.032 | 39.968 | 39.732 | 38.994 | 38.899 | 0.095 | 38.344 | 37.975 |
| M42 × 4.5 | 6g | 0.063 | 41.937 | 41.437 | 39.014 | 38.778 | 0.236 | 37.065 | 36.006 |
| M42 × 4.5 | 6h | 0.000 | 42.000 | 41.500 | 39.077 | 38.841 | 0.236 | 37.128 | 36.069 |
| M42 × 4.5 | 4g6g | 0.063 | 41.937 | 41.437 | 39.014 | 38.864 | 0.150 | 37.065 | 36.092 |
| M42 × 2 | 6g | 0.038 | 41.962 | 41.682 | 40.663 | 40.493 | 0.170 | 39.797 | 39.261 |
| M42 × 2 | 6h | 0.000 | 42.000 | 41.720 | 40.701 | 40.531 | 0.170 | 39.835 | 39.299 |
| M42 × 2 | 4g6g | 0.038 | 41.962 | 41.682 | 40.663 | 40.557 | 0.106 | 39.797 | 39.325 |
| M45 × 1.5 | 6g | 0.032 | 44.968 | 44.732 | 43.994 | 43.844 | 0.150 | 43.344 | 42.920 |
| M45 × 1.5 | 6h | 0.000 | 45.000 | 44.764 | 44.026 | 43.876 | 0.150 | 43.376 | 42.952 |
| M45 × 1.5 | 4g6g | 0.032 | 44.968 | 44.732 | 43.994 | 43.899 | 0.095 | 43.344 | 42.975 |
| M48 × 5 | 6g | 0.071 | 47.929 | 47.399 | 44.681 | 44.431 | 0.250 | 42.516 | 41.351 |
| M48 × 5 | 6h | 0.000 | 48.000 | 47.470 | 44.752 | 44.502 | 0.250 | 42.587 | 41.422 |
| M48 × 5 | 4g6g | 0.071 | 47.929 | 47.399 | 44.681 | 44.521 | 0.160 | 42.516 | 41.441 |
| M48 × 2 | 6g | 0.038 | 47.962 | 47.682 | 46.663 | 46.483 | 0.180 | 45.797 | 45.251 |
| M48 × 2 | 6h | 0.000 | 48.000 | 47.720 | 46.701 | 46.521 | 0.180 | 45.835 | 45.289 |
| M48 × 2 | 4g6g | 0.038 | 47.962 | 47.682 | 46.663 | 46.551 | 0.112 | 45.797 | 45.319 |
| M50 × 1.5 | 6g | 0.032 | 49.968 | 49.732 | 48.994 | 48.834 | 0.160 | 48.344 | 47.910 |
| M50 × 1.5 | 6h | 0.000 | 50.000 | 49.764 | 49.026 | 48.866 | 0.160 | 48.376 | 47.942 |
| M50 × 1.5 | 4g6g | 0.032 | 49.968 | 49.732 | 48.994 | 48.894 | 0.100 | 48.344 | 47.970 |
| M55 × 1.5 | 6g | 0.032 | 54.968 | 54.732 | 53.994 | 53.834 | 0.160 | 53.344 | 52.910 |
| M55 × 1.5 | 6h | 0.000 | 55.000 | 54.764 | 54.026 | 53.866 | 0.160 | 53.376 | 52.942 |
| M55 × 1.5 | 4g6g | 0.032 | 54.968 | 54.732 | 53.994 | 53.894 | 0.100 | 53.344 | 52.970 |
| M56 × 5.5 | 6g | 0.075 | 55.925 | 55.365 | 52.353 | 52.088 | 0.265 | 49.971 | 48.700 |
| M56 × 5.5 | 6h | 0.000 | 56.000 | 55.440 | 52.428 | 52.163 | 0.265 | 50.046 | 48.775 |
| M56 × 5.5 | 4g6g | 0.075 | 55.925 | 55.365 | 52.353 | 52.183 | 0.170 | 49.971 | 48.795 |
| M56 × 2 | 6g | 0.038 | 55.962 | 55.682 | 54.663 | 54.483 | 0.180 | 53.797 | 53.251 |
| M56 × 2 | 6h | 0.000 | 56.000 | 55.720 | 54.701 | 54.521 | 0.180 | 53.835 | 53.289 |
| M56 × 2 | 4g6g | 0.038 | 55.962 | 55.682 | 54.663 | 54.551 | 0.112 | 53.797 | 53.319 |
| M60 × 1.5 | 6g | 0.032 | 59.968 | 59.732 | 58.994 | 58.834 | 0.160 | 58.344 | 57.910 |
| M60 × 1.5 | 6h | 0.000 | 60.000 | 59.764 | 59.026 | 58.866 | 0.160 | 58.376 | 57.942 |
| M60 × 1.5 | 4g6g | 0.032 | 59.968 | 59.732 | 58.994 | 58.894 | 0.100 | 58.344 | 57.970 |
| M64 × 6 | 6g | 0.080 | 63.920 | 63.320 | 60.023 | 59.743 | 0.280 | 57.425 | 56.047 |
| M64 × 6 | 6h | 0.000 | 64.000 | 63.400 | 60.103 | 59.823 | 0.280 | 57.505 | 56.127 |
| M64 × 6 | 4g6g | 0.080 | 63.920 | 63.320 | 60.023 | 59.843 | 0.180 | 57.425 | 56.147 |
| M64 × 2 | 6g | 0.038 | 63.962 | 63.682 | 62.663 | 62.483 | 0.180 | 61.797 | 61.251 |
| M64 × 2 | 6h | 0.000 | 64.000 | 63.720 | 62.701 | 62.521 | 0.180 | 61.835 | 61.289 |
| M64 × 2 | 4g6g | 0.038 | 63.962 | 63.682 | 62.663 | 62.551 | 0.112 | 61.797 | 61.319 |
| M65 × 1.5 | 6g | 0.032 | 64.968 | 64.732 | 63.994 | 63.834 | 0.160 | 63.344 | 62.910 |
| M65 × 1.5 | 6h | 0.000 | 65.000 | 64.764 | 64.026 | 63.866 | 0.160 | 63.376 | 62.942 |
| M65 × 1.5 | 4g6g | 0.032 | 64.968 | 64.732 | 63.994 | 63.894 | 0.100 | 63.344 | 62.970 |
| M70 × 1.5 | 6g | 0.032 | 69.968 | 69.732 | 68.994 | 68.834 | 0.160 | 68.344 | 67.910 |
| M70 × 1.5 | 6h | 0.000 | 70.000 | 69.764 | 69.026 | 68.866 | 0.160 | 68.376 | 67.942 |
| M70 × 1.5 | 4g6g | 0.032 | 69.968 | 69.732 | 68.994 | 68.894 | 0.100 | 68.344 | 67.970 |
| M72 × 6 | 6g | 0.080 | 71.920 | 71.320 | 68.023 | 67.743 | 0.280 | 65.425 | 64.047 |
| M72 × 6 | 6h | 0.000 | 72.000 | 71.400 | 68.103 | 67.823 | 0.280 | 65.505 | 64.127 |
| M72 × 6 | 4g6g | 0.080 | 71.920 | 71.320 | 68.023 | 67.843 | 0.180 | 65.425 | 64.147 |
| M72 × 2 | 6g | 0.038 | 71.962 | 71.682 | 70.663 | 70.483 | 0.180 | 69.797 | 69.251 |
| M72 × 2 | 6h | 0.000 | 72.000 | 71.720 | 70.701 | 70.521 | 0.180 | 69.835 | 69.289 |
| M72 × 2 | 4g6g | 0.038 | 71.962 | 71.682 | 70.663 | 70.551 | 0.112 | 69.797 | 69.319 |
| M75 × 1.5 | 6g | 0.032 | 74.968 | 74.732 | 73.994 | 73.834 | 0.160 | 73.344 | 72.910 |
| M75 × 1.5 | 6h | 0.000 | 75.000 | 74.764 | 74.026 | 73.866 | 0.160 | 73.376 | 72.942 |
| M75 × 1.5 | 4g6g | 0.032 | 74.968 | 74.732 | 73.994 | 73.894 | 0.100 | 73.344 | 72.970 |
| M80 × 6 | 6g | 0.080 | 79.920 | 79.320 | 76.023 | 75.743 | 0.280 | 73.425 | 72.047 |
| M80 × 6 | 6h | 0.000 | 80.000 | 79.400 | 76.103 | 75.823 | 0.280 | 73.505 | 72.127 |
| M80 × 6 | 4g6g | 0.080 | 79.920 | 79.320 | 76.023 | 75.843 | 0.180 | 73.425 | 72.147 |
| M80 × 2 | 6g | 0.038 | 79.962 | 79.682 | 78.663 | 78.483 | 0.180 | 77.797 | 77.251 |
| M80 × 2 | 6h | 0.000 | 80.000 | 79.720 | 78.701 | 78.521 | 0.180 | 77.835 | 77.289 |
| M80 × 2 | 4g6g | 0.038 | 79.962 | 79.682 | 78.663 | 78.551 | 0.112 | 77.797 | 77.319 |
| M80 × 1.5 | 6g | 0.032 | 79.968 | 79.732 | 78.994 | 78.834 | 0.160 | 78.344 | 77.910 |
| M80 × 1.5 | 6h | 0.000 | 80.000 | 79.764 | 79.026 | 78.866 | 0.160 | 78.376 | 77.942 |
| M80 × 1.5 | 4g6g | 0.032 | 79.968 | 79.732 | 78.994 | 78.894 | 0.100 | 78.344 | 77.970 |
| M85 × 2 | 6g | 0.038 | 84.962 | 84.682 | 83.663 | 83.483 | 0.180 | 82.797 | 82.251 |
| M85 × 2 | 6h | 0.000 | 85.000 | 84.720 | 83.701 | 83.521 | 0.180 | 82.835 | 82.289 |

Table 12. (Continued) External Metric Thread—M Profile Limiting Dimensions ANSI/ASME B1.13M-2001

| Basic Thread Designation | Tol. Class | Allowance ^a <i>es</i> | Major Diameter ^b <i>d</i> | | Pitch Diameter ^{b c} <i>d</i> ₂ | | | Minor Dia. ^b <i>d</i> ₁ | Minor Dia. ^d <i>d</i> ₃ |
|--------------------------|------------|-------------------------------------|---|---------|--|---------|-------|--|--|
| | | | Max. | Min. | Max. | Min. | Tol. | | |
| M85 × 2 | 4g6g | 0.038 | 84.962 | 84.682 | 83.663 | 83.551 | 0.112 | 82.797 | 82.319 |
| M90 × 6 | 6g | 0.080 | 89.920 | 89.320 | 86.023 | 85.743 | 0.280 | 83.425 | 82.047 |
| M90 × 6 | 6h | 0.000 | 90.000 | 89.400 | 86.103 | 85.823 | 0.280 | 83.505 | 82.127 |
| M90 × 6 | 4g6g | 0.080 | 89.920 | 89.320 | 86.023 | 85.843 | 0.180 | 83.425 | 82.147 |
| M90 × 2 | 6g | 0.038 | 89.962 | 89.682 | 88.663 | 88.483 | 0.180 | 87.797 | 87.251 |
| M90 × 2 | 6h | 0.000 | 90.000 | 89.720 | 88.701 | 88.521 | 0.180 | 87.835 | 87.289 |
| M90 × 2 | 4g6g | 0.038 | 89.962 | 89.682 | 88.663 | 88.551 | 0.112 | 87.797 | 87.319 |
| M95 × 2 | 6g | 0.038 | 94.962 | 94.682 | 93.663 | 93.473 | 0.190 | 92.797 | 92.241 |
| M95 × 2 | 6h | 0.000 | 95.000 | 94.720 | 93.701 | 93.511 | 0.190 | 92.835 | 92.279 |
| M95 × 2 | 4g6g | 0.038 | 94.962 | 94.682 | 93.663 | 93.545 | 0.118 | 92.797 | 92.313 |
| M100 × 6 | 6g | 0.080 | 99.920 | 99.320 | 96.023 | 95.723 | 0.300 | 93.425 | 92.027 |
| M100 × 6 | 6h | 0.000 | 100.000 | 99.400 | 96.103 | 95.803 | 0.300 | 93.505 | 92.107 |
| M100 × 6 | 4g6g | 0.080 | 99.920 | 99.320 | 96.023 | 95.833 | 0.190 | 93.425 | 92.137 |
| M100 × 2 | 6g | 0.038 | 99.962 | 99.682 | 98.663 | 98.473 | 0.190 | 97.797 | 97.241 |
| M100 × 2 | 6h | 0.000 | 100.000 | 99.720 | 98.701 | 98.511 | 0.190 | 97.835 | 97.279 |
| M100 × 2 | 4g6g | 0.038 | 99.962 | 99.682 | 98.663 | 98.545 | 0.118 | 97.797 | 97.313 |
| M105 × 2 | 6g | 0.038 | 104.962 | 104.682 | 103.663 | 103.473 | 0.190 | 102.797 | 102.241 |
| M105 × 2 | 6h | 0.000 | 105.000 | 104.720 | 103.701 | 103.511 | 0.190 | 102.835 | 102.279 |
| M105 × 2 | 4g6g | 0.038 | 104.962 | 104.682 | 103.663 | 103.545 | 0.118 | 102.797 | 102.313 |
| M110 × 2 | 6g | 0.038 | 109.962 | 109.682 | 108.663 | 108.473 | 0.190 | 107.797 | 107.241 |
| M110 × 2 | 6h | 0.000 | 110.000 | 109.720 | 108.701 | 108.511 | 0.190 | 107.835 | 107.279 |
| M110 × 2 | 4g6g | 0.038 | 109.962 | 109.682 | 108.663 | 108.545 | 0.118 | 107.797 | 107.313 |
| M120 × 2 | 6g | 0.038 | 119.962 | 119.682 | 118.663 | 118.473 | 0.190 | 117.797 | 117.241 |
| M120 × 2 | 6h | 0.000 | 120.000 | 119.720 | 118.701 | 118.511 | 0.190 | 117.835 | 117.279 |
| M120 × 2 | 4g6g | 0.038 | 119.962 | 119.682 | 118.663 | 118.545 | 0.118 | 117.797 | 117.313 |
| M130 × 2 | 6g | 0.038 | 129.962 | 129.682 | 128.663 | 128.473 | 0.190 | 127.797 | 127.241 |
| M130 × 2 | 6h | 0.000 | 130.000 | 129.720 | 128.701 | 128.511 | 0.190 | 127.835 | 127.279 |
| M130 × 2 | 4g6g | 0.038 | 129.962 | 129.682 | 128.663 | 128.545 | 0.118 | 127.797 | 127.313 |
| M140 × 2 | 6g | 0.038 | 139.962 | 139.682 | 138.663 | 138.473 | 0.190 | 137.797 | 137.241 |
| M140 × 2 | 6h | 0.000 | 140.000 | 139.720 | 138.701 | 138.511 | 0.190 | 137.835 | 137.279 |
| M140 × 2 | 4g6g | 0.038 | 139.962 | 139.682 | 138.663 | 138.545 | 0.118 | 137.797 | 137.313 |
| M150 × 2 | 6g | 0.038 | 149.962 | 149.682 | 148.663 | 148.473 | 0.190 | 147.797 | 147.241 |
| M150 × 2 | 6h | 0.000 | 150.000 | 149.720 | 148.701 | 148.511 | 0.190 | 147.835 | 147.279 |
| M150 × 2 | 4g6g | 0.038 | 149.962 | 149.682 | 148.663 | 148.545 | 0.118 | 147.797 | 147.313 |
| M160 × 3 | 6g | 0.048 | 159.952 | 159.577 | 158.003 | 157.779 | 0.224 | 156.704 | 155.931 |
| M160 × 3 | 6h | 0.000 | 160.000 | 159.625 | 158.051 | 157.827 | 0.224 | 156.752 | 155.979 |
| M160 × 3 | 4g6g | 0.048 | 159.952 | 159.577 | 158.003 | 157.863 | 0.140 | 156.704 | 156.015 |
| M170 × 3 | 6g | 0.048 | 169.952 | 169.577 | 168.003 | 167.779 | 0.224 | 166.704 | 165.931 |
| M170 × 3 | 6h | 0.000 | 170.000 | 169.625 | 168.051 | 167.827 | 0.224 | 166.752 | 165.979 |
| M170 × 3 | 4g6g | 0.048 | 169.952 | 169.577 | 168.003 | 167.863 | 0.140 | 166.704 | 166.015 |
| M180 × 3 | 6g | 0.048 | 179.952 | 179.577 | 178.003 | 177.779 | 0.224 | 176.704 | 175.931 |
| M180 × 3 | 6h | 0.000 | 180.000 | 179.625 | 178.051 | 177.827 | 0.224 | 176.752 | 175.979 |
| M180 × 3 | 4g6g | 0.048 | 179.952 | 179.577 | 178.003 | 177.863 | 0.140 | 176.704 | 176.015 |
| M190 × 3 | 6g | 0.048 | 189.952 | 189.577 | 188.003 | 187.753 | 0.250 | 186.704 | 185.905 |
| M190 × 3 | 6h | 0.000 | 190.000 | 189.625 | 188.051 | 187.801 | 0.250 | 186.752 | 185.953 |
| M190 × 3 | 4g6g | 0.048 | 189.952 | 189.577 | 188.003 | 187.843 | 0.160 | 186.704 | 185.995 |
| M200 × 3 | 6g | 0.048 | 199.952 | 199.577 | 198.003 | 197.753 | 0.250 | 196.704 | 195.905 |
| M200 × 3 | 6h | 0.000 | 200.000 | 199.625 | 198.051 | 197.801 | 0.250 | 196.752 | 195.953 |
| M200 × 3 | 4g6g | 0.048 | 199.952 | 199.577 | 198.003 | 197.843 | 0.160 | 196.704 | 195.995 |

^a *es* is an absolute value.

^b For coated threads with tolerance classes 6g or 4g6g.

^c Functional diameter size includes the effects of all variations in pitch diameter, thread form, and profile. The variations in the individual thread characteristics such as flank angle, lead, taper, and roundness on a given thread, cause the measurements of the pitch diameter and functional diameter to vary from one another on most threads. The pitch diameter and the functional diameter on a given thread are equal to one another only when the thread form is perfect. When required to inspect either the pitch diameter, the functional diameter, or both, for thread acceptance, use the same limits of size for the appropriate thread size and class.

^d Dimension used in the design of tools, etc. in dimensioning external threads it is not normally specified. Generally, minor diameter acceptance is based on maximum material condition gaging.

All dimensions are in millimeters.

FASTENER INFORMATION

Table 1. Grade Identification Marks and Mechanical Properties of Bolts and Screws

| Identifier | Grade | Size (in.) | Min. Strength (10^3 psi) | | | Material & Treatment |
|------------|------------------------|----------------------------------|--------------------------------|-----|-----|----------------------------|
| | SAE Grade 1 | $\frac{1}{4}$ to $1\frac{1}{2}$ | 33 | 60 | 36 | 1 |
| A | ASTM A307 | $\frac{1}{4}$ to $1\frac{1}{2}$ | 33 | 60 | 36 | 3 |
| | SAE Grade 2 | $\frac{1}{4}$ to $\frac{3}{4}$ | 55 | 74 | 57 | 1 |
| | | $\frac{7}{8}$ to $1\frac{1}{2}$ | 33 | 60 | 36 | |
| | SAE Grade 4 | $\frac{1}{4}$ to $1\frac{1}{2}$ | 65 | 115 | 100 | 2,a |
| B | SAE Grade 5, ASTM A449 | $\frac{1}{4}$ to 1 | 85 | 120 | 92 | 2,b |
| | ASTM A449 | $1\frac{1}{8}$ to $1\frac{1}{2}$ | 74 | 105 | 81 | |
| | ASTM A449 | $1\frac{3}{4}$ to 3 | 55 | 90 | 58 | |
| C | SAE Grade 5.2 | $\frac{1}{4}$ to 1 | 85 | 120 | 92 | 4,b |
| D | ASTM A325, Type 1 | $\frac{1}{2}$ to 1 | 85 | 120 | 92 | 2,b |
| | | $1\frac{1}{8}$ to $1\frac{1}{2}$ | 74 | 105 | 81 | |
| E | ASTM A325, Type 2 | $\frac{1}{2}$ to 1 | 85 | 120 | 92 | 4,b |
| | | $1\frac{1}{8}$ to $1\frac{1}{2}$ | 74 | 105 | 81 | |
| F | ASTM A325, Type 3 | $\frac{1}{2}$ to 1 | 85 | 120 | 92 | 5,b |
| | | $1\frac{1}{8}$ to $1\frac{1}{2}$ | 74 | 105 | 81 | |
| G | ASTM A354, Grade BC | $\frac{1}{4}$ to $2\frac{1}{2}$ | 105 | 125 | 109 | 5,b |
| | | $2\frac{5}{8}$ to 4 | 95 | 115 | 99 | |
| H | SAE Grade 7 | $\frac{1}{4}$ to $1\frac{1}{2}$ | 105 | 133 | 115 | 7,b |
| I | SAE Grade 8 | $\frac{1}{4}$ to $1\frac{1}{2}$ | 120 | 150 | 130 | 7,b |
| | ASTM A354, Grade BD | $\frac{1}{4}$ to $2\frac{1}{2}$ | 120 | 150 | 130 | 6,b |
| | | $2\frac{5}{8}$ to 4 | 105 | 140 | 115 | |
| J | SAE Grade 8.2 | $\frac{1}{4}$ to 1 | 120 | 150 | 130 | 4,b |
| K | ASTM A490, Type 1 | $\frac{1}{2}$ to $1\frac{1}{2}$ | 120 | 150 | 130 | 6,b |
| L | ASTM A490, Type 3 | | | | | 5,b |

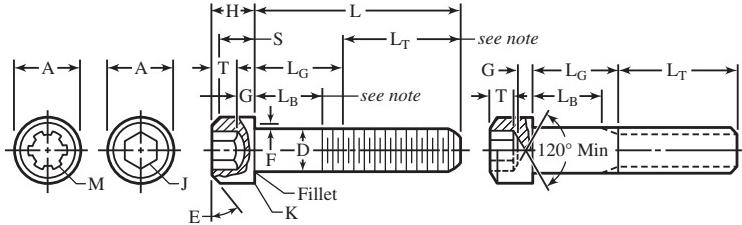
Material Steel: 1—low or medium carbon; 2—medium carbon; 3—low carbon; 4—low-carbon martensite; 5—weathering steel; 6—alloy steel; 7—medium-carbon alloy. Treatment: a—cold drawn; b—quench and temper.

Table 2. Applicability of Hexagon and Spline Keys and Bits

| Nominal Key or Bit Size | Cap Screws 1960 Series | Flat Counter sunk Head Cap Screws | Button Head Cap Screws | Shoulder Screws | Set Screws | Nominal Screw Sizes |
|-------------------------|--------------------------------|-----------------------------------|---------------------------------|-----------------|----------------|---------------------------------|
| | | | | | | HEXAGON KEYS AND BITS |
| 0.028 | ... | ... | ... | ... | ... | 0 |
| 0.035 | ... | 0 | 0 | ... | ... | 1 & 2 |
| 0.050 | 0 | 1 & 2 | 1 & 2 | ... | ... | 3 & 4 |
| $\frac{1}{16}$ | 0.062 | 1 | 3 & 4 | 3 & 4 | ... | 5 & 6 |
| $\frac{5}{64}$ | 0.078 | 2 & 3 | 5 & 6 | 5 & 6 | ... | 8 |
| $\frac{3}{32}$ | 0.094 | 4 & 5 | 8 | 8 | ... | 10 |
| $\frac{7}{64}$ | 0.109 | 6 | ... | ... | ... | ... |
| $\frac{1}{8}$ | 0.125 | ... | 10 | 10 | $\frac{1}{4}$ | $\frac{1}{4}$ |
| $\frac{9}{64}$ | 0.141 | 8 | ... | ... | ... | ... |
| $\frac{5}{32}$ | 0.156 | 10 | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{5}{16}$ |
| $\frac{3}{16}$ | 0.188 | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{8}$ |
| $\frac{7}{32}$ | 0.219 | ... | $\frac{3}{8}$ | $\frac{3}{8}$ | ... | $\frac{7}{16}$ |
| $\frac{1}{4}$ | 0.250 | $\frac{5}{16}$ | $\frac{7}{16}$ | ... | $\frac{1}{2}$ | $\frac{1}{2}$ |
| $\frac{5}{16}$ | 0.312 | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{5}{8}$ |
| $\frac{3}{8}$ | 0.375 | $\frac{7}{16}$ & $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{3}{4}$ |
| $\frac{7}{16}$ | 0.438 | ... | ... | ... | ... | ... |
| $\frac{1}{2}$ | 0.500 | $\frac{5}{8}$ | $\frac{3}{4}$ | ... | 1 | $\frac{7}{8}$ |
| $\frac{9}{16}$ | 0.562 | ... | $\frac{7}{8}$ | ... | ... | 1 & $1\frac{1}{8}$ |
| $\frac{5}{8}$ | 0.625 | $\frac{3}{4}$ | 1 | ... | $1\frac{1}{4}$ | $1\frac{1}{4}$ & $1\frac{1}{8}$ |
| $\frac{3}{4}$ | 0.750 | $\frac{7}{8}$ & 1 | $1\frac{1}{8}$ | ... | ... | $1\frac{1}{2}$ |
| $\frac{7}{8}$ | 0.875 | $1\frac{1}{8}$ & $1\frac{1}{4}$ | $1\frac{1}{4}$ & $1\frac{3}{8}$ | ... | $1\frac{1}{2}$ | ... |
| 1 | 1.000 | $1\frac{3}{8}$ & $1\frac{1}{2}$ | $1\frac{1}{2}$ | ... | $1\frac{3}{4}$ | $1\frac{3}{4}$ & 2 |
| $1\frac{1}{4}$ | 1.250 | $1\frac{3}{4}$ | ... | ... | 2 | ... |
| $1\frac{1}{2}$ | 1.500 | 2 | ... | ... | ... | ... |
| $1\frac{3}{4}$ | 1.750 | $2\frac{1}{4}$ & $2\frac{1}{2}$ | ... | ... | ... | ... |
| 2 | 2.000 | $2\frac{3}{4}$ | ... | ... | ... | ... |
| $2\frac{1}{4}$ | 2.250 | 3 & $3\frac{1}{4}$ | ... | ... | ... | ... |
| $2\frac{3}{4}$ | 2.750 | $3\frac{1}{2}$ & $3\frac{3}{4}$ | ... | ... | ... | ... |
| 3 | 3.000 | 4 | ... | ... | ... | ... |
| SPLINE KEYS AND BITS | | | | | | |
| 0.033 | ... | ... | ... | ... | ... | 0 & 1 |
| 0.048 | ... | 0 | 0 | ... | ... | 2 & 3 |
| 0.060 | 0 | 1 & 2 | 1 & 2 | ... | ... | 4 |
| 0.072 | 1 | 3 & 4 | 3 & 4 | ... | ... | 5 & 6 |
| 0.096 | 2 & 3 | 5 & 6 | 5 & 6 | ... | ... | 8 |
| 0.111 | 4 & 5 | 8 | 8 | ... | ... | 10 |
| 0.133 | 6 | ... | ... | ... | ... | ... |
| 0.145 | ... | 10 | 10 | ... | ... | $\frac{1}{4}$ |
| 0.168 | 8 | ... | ... | ... | ... | ... |
| 0.183 | 10 | $\frac{1}{4}$ | $\frac{1}{4}$ | ... | ... | $\frac{5}{16}$ |
| 0.216 | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | ... | ... | $\frac{3}{8}$ |
| 0.251 | ... | $\frac{3}{8}$ | $\frac{3}{8}$ | ... | ... | $\frac{7}{16}$ |
| 0.291 | $\frac{5}{16}$ | $\frac{7}{16}$ | ... | ... | ... | $\frac{1}{2}$ |
| 0.372 | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | ... | ... | $\frac{5}{8}$ |
| 0.454 | $\frac{7}{16}$ & $\frac{1}{2}$ | $\frac{5}{8}$ & $\frac{3}{4}$ | $\frac{5}{8}$ | ... | ... | $\frac{3}{4}$ |
| 0.595 | $\frac{5}{8}$ | ... | ... | ... | ... | $\frac{7}{8}$ |
| 0.620 | $\frac{3}{4}$ | ... | ... | ... | ... | ... |
| 0.698 | $\frac{7}{8}$ | ... | ... | ... | ... | ... |
| 0.790 | 1 | ... | ... | ... | ... | ... |

Source: Appendix to American National Standard ANSI/ASME B18.3-1998.

Table 3. American National Standard Hexagon and Spline Socket Head Cap Screws 1960 Series ANSI/ASME B18.3-1986, R1995



| Nominal Size | Body Diameter, | | Head Diameter, | | Head Height, | | Spline Socket Size | Hex.Socket Size | Fillet Ext. | Key Engagement ^a |
|----------------|----------------|--------|----------------|-------|--------------|-------|--------------------|-----------------|-------------|-----------------------------|
| | Max | Min | Max | Min | Max | Min | | | | |
| | D | | A | | H | | M | J | F | |
| 0 | 0.0600 | 0.0568 | 0.096 | 0.091 | 0.060 | 0.057 | 0.060 | 0.050 | 0.007 | 0.025 |
| 1 | 0.0730 | 0.0695 | 0.118 | 0.112 | 0.073 | 0.070 | 0.072 | $\frac{1}{16}$ | 0.062 | 0.007 |
| 2 | 0.0860 | 0.0822 | 0.140 | 0.134 | 0.086 | 0.083 | 0.096 | $\frac{5}{64}$ | 0.078 | 0.008 |
| 3 | 0.0990 | 0.0949 | 0.161 | 0.154 | 0.099 | 0.095 | 0.096 | $\frac{3}{64}$ | 0.078 | 0.008 |
| 4 | 0.1120 | 0.1075 | 0.183 | 0.176 | 0.112 | 0.108 | 0.111 | $\frac{3}{32}$ | 0.094 | 0.009 |
| 5 | 0.1250 | 0.1202 | 0.205 | 0.198 | 0.125 | 0.121 | 0.111 | $\frac{3}{32}$ | 0.094 | 0.010 |
| 6 | 0.1380 | 0.1329 | 0.226 | 0.218 | 0.138 | 0.134 | 0.133 | $\frac{7}{64}$ | 0.109 | 0.010 |
| 8 | 0.1640 | 0.1585 | 0.270 | 0.262 | 0.164 | 0.159 | 0.168 | $\frac{9}{64}$ | 0.141 | 0.012 |
| 10 | 0.1900 | 0.1840 | 0.312 | 0.303 | 0.190 | 0.185 | 0.183 | $\frac{5}{32}$ | 0.156 | 0.014 |
| $\frac{1}{4}$ | 0.2500 | 0.2435 | 0.375 | 0.365 | 0.250 | 0.244 | 0.216 | $\frac{3}{16}$ | 0.188 | 0.014 |
| $\frac{5}{16}$ | 0.3125 | 0.3053 | 0.469 | 0.457 | 0.312 | 0.306 | 0.291 | $\frac{1}{4}$ | 0.250 | 0.017 |
| $\frac{3}{8}$ | 0.3750 | 0.3678 | 0.562 | 0.550 | 0.375 | 0.368 | 0.372 | $\frac{5}{16}$ | 0.312 | 0.020 |
| $\frac{7}{16}$ | 0.4375 | 0.4294 | 0.656 | 0.642 | 0.438 | 0.430 | 0.454 | $\frac{3}{8}$ | 0.375 | 0.023 |
| $\frac{1}{2}$ | 0.5000 | 0.4919 | 0.750 | 0.735 | 0.500 | 0.492 | 0.454 | $\frac{3}{8}$ | 0.375 | 0.026 |
| $\frac{5}{8}$ | 0.6250 | 0.6163 | 0.938 | 0.921 | 0.625 | 0.616 | 0.595 | $\frac{1}{2}$ | 0.500 | 0.032 |
| $\frac{3}{4}$ | 0.7500 | 0.7406 | 1.125 | 1.107 | 0.750 | 0.740 | 0.620 | $\frac{5}{8}$ | 0.625 | 0.039 |
| $\frac{7}{8}$ | 0.8750 | 0.8647 | 1.312 | 1.293 | 0.875 | 0.864 | 0.698 | $\frac{3}{4}$ | 0.750 | 0.044 |
| 1 | 1.0000 | 0.9886 | 1.500 | 1.479 | 1.000 | 0.988 | 0.790 | $\frac{3}{4}$ | 0.750 | 0.050 |
| $1\frac{1}{8}$ | 1.1250 | 1.1086 | 1.688 | 1.665 | 1.125 | 1.111 | ... | $\frac{7}{8}$ | 0.875 | 0.055 |
| $1\frac{1}{4}$ | 1.2500 | 1.2336 | 1.875 | 1.852 | 1.250 | 1.236 | ... | $\frac{7}{8}$ | 0.875 | 0.060 |
| $1\frac{1}{2}$ | 1.3750 | 1.3568 | 2.062 | 2.038 | 1.375 | 1.360 | ... | 1 | 1.000 | 0.065 |
| $1\frac{3}{4}$ | 1.5000 | 1.4818 | 2.250 | 2.224 | 1.500 | 1.485 | ... | 1 | 1.000 | 0.070 |
| $1\frac{7}{8}$ | 1.7500 | 1.7295 | 2.625 | 2.597 | 1.750 | 1.734 | ... | $1\frac{1}{4}$ | 1.250 | 0.080 |
| 2 | 2.0000 | 1.9780 | 3.000 | 2.970 | 2.000 | 1.983 | ... | $1\frac{1}{2}$ | 1.500 | 0.090 |
| $2\frac{1}{4}$ | 2.2500 | 2.2280 | 3.375 | 3.344 | 2.250 | 2.232 | ... | $1\frac{3}{4}$ | 1.750 | 0.100 |
| $2\frac{1}{2}$ | 2.5000 | 2.4762 | 3.750 | 3.717 | 2.500 | 2.481 | ... | $1\frac{3}{4}$ | 1.750 | 0.110 |
| $2\frac{3}{4}$ | 2.7500 | 2.7262 | 4.125 | 4.090 | 2.750 | 2.730 | ... | 2 | 2.000 | 0.120 |
| 3 | 3.0000 | 2.9762 | 4.500 | 4.464 | 3.000 | 2.979 | ... | $2\frac{1}{4}$ | 2.250 | 0.130 |
| $3\frac{1}{4}$ | 3.2500 | 3.2262 | 4.875 | 4.837 | 3.250 | 3.228 | ... | $2\frac{1}{4}$ | 2.250 | 0.140 |
| $3\frac{1}{2}$ | 3.5000 | 3.4762 | 5.250 | 5.211 | 3.500 | 3.478 | ... | $2\frac{3}{4}$ | 2.750 | 0.150 |
| $3\frac{3}{4}$ | 3.7500 | 3.7262 | 5.625 | 5.584 | 3.750 | 3.727 | ... | $2\frac{3}{4}$ | 2.750 | 0.160 |
| 4 | 4.0000 | 3.9762 | 6.000 | 5.958 | 4.000 | 3.976 | ... | 3 | 3.000 | 0.170 |
| | | | | | | | | | | 1.995 |

^a(Key engagement depths are minimum.)

All dimensions in inches. The body length L_B of the screw is the length of the unthreaded cylindrical portion of the shank. The length of thread, L_T , is the distance from the extreme point to the last complete (full form) thread. Standard length increments for screw diameters up to 1 inch are $\frac{1}{16}$ inch for lengths $\frac{1}{8}$ through $\frac{1}{4}$ inch, $\frac{1}{8}$ inch for lengths $\frac{1}{4}$ through 1 inch, $\frac{1}{4}$ inch for lengths 1 through $3\frac{1}{2}$ inches, $\frac{1}{2}$ inch for lengths $3\frac{1}{2}$ through 7 inches, 1 inch for lengths 7 through 10 inches and for diameters over 1 inch are $\frac{1}{2}$ inch for lengths 1 through 7 inches, 1 inch for lengths 7 through 10 inches, and 2 inches for lengths over 10 inches. Heads may be plain or knurled, and chamfered to an angle E of 30 to 45 degrees with the surface of the flat. The thread conforms to the Unified Standard with radius root, Class 3A UNRC and UNRF for screw sizes No. 0 through 1 inch inclusive, Class 2A UNRC and UNRF for over 1 inch through $1\frac{1}{2}$ inches inclusive, and Class 2A UNRC for larger sizes. For details not shown, including materials, see ANSI/ASME B18.3-1998.

**Table 4. American National Standard Socket Head Cap Screws—Metric Series
ANSI/ASME B18.3.1M-1986, R2002**

The technical drawings illustrate the geometric features of a metric socket head cap screw. The top row shows front and side views of the head. The bottom row shows a side view of the shank with a 120° minimum chamfer angle and a cross-sectional view of the spline socket.

| Nominal Size and Thread Pitch | Body Diameter, <i>D</i> | | Head Diameter <i>A</i> | | Head Height <i>H</i> | | Chamfer or Radius <i>S</i> | Hexagonal Socket Size ^a <i>J</i> | Spline Socket Size ^a <i>M</i> | Key Engagement <i>T</i> | Transition Dia. <i>B</i> ^a |
|-------------------------------|-------------------------|-------|------------------------|-------|----------------------|-------|----------------------------|---|--|-------------------------|---------------------------------------|
| | Max | Min | Max | Min | Max | Min | | | | | |
| M1.6 × 0.35 | 1.60 | 1.46 | 3.00 | 2.87 | 1.60 | 1.52 | 0.16 | 1.5 | 1.829 | 0.80 | 2.0 |
| M2 × 0.4 | 2.00 | 1.86 | 3.80 | 3.65 | 2.00 | 1.91 | 0.20 | 1.5 | 1.829 | 1.00 | 2.6 |
| M2.5 × 0.45 | 2.50 | 2.36 | 4.50 | 4.33 | 2.50 | 2.40 | 0.25 | 2.0 | 2.438 | 1.25 | 3.1 |
| M3 × 0.5 | 3.00 | 2.86 | 5.50 | 5.32 | 3.00 | 2.89 | 0.30 | 2.5 | 2.819 | 1.50 | 3.6 |
| M4 × 0.7 | 4.00 | 3.82 | 7.00 | 6.80 | 4.00 | 3.88 | 0.40 | 3.0 | 3.378 | 2.00 | 4.7 |
| M5 × 0.8 | 5.00 | 4.82 | 8.50 | 8.27 | 5.00 | 4.86 | 0.50 | 4.0 | 4.648 | 2.50 | 5.7 |
| M6 × 1 | 6.00 | 5.82 | 10.00 | 9.74 | 6.00 | 5.85 | 0.60 | 5.0 | 5.486 | 3.00 | 6.8 |
| M8 × 1.25 | 8.00 | 7.78 | 13.00 | 12.70 | 8.00 | 7.83 | 0.80 | 6.0 | 7.391 | 4.00 | 9.2 |
| M10 × 1.5 | 10.00 | 9.78 | 16.00 | 15.67 | 10.00 | 9.81 | 1.00 | 8.0 | ... | 5.00 | 11.2 |
| M12 × 1.75 | 12.00 | 11.73 | 18.00 | 17.63 | 12.00 | 11.79 | 1.20 | 10.0 | ... | 6.00 | 14.2 |
| M14 × 2 ^b | 14.00 | 13.73 | 21.00 | 20.60 | 14.00 | 13.77 | 1.40 | 12.0 | ... | 7.00 | 16.2 |
| M16 × 2 | 16.00 | 15.73 | 24.00 | 23.58 | 16.00 | 15.76 | 1.60 | 14.0 | ... | 8.00 | 18.2 |
| M20 × 2.5 | 20.00 | 19.67 | 30.00 | 29.53 | 20.00 | 19.73 | 2.00 | 17.0 | ... | 10.00 | 22.4 |
| M24 × 3 | 24.00 | 23.67 | 36.00 | 35.48 | 24.00 | 23.70 | 2.40 | 19.0 | ... | 12.00 | 26.4 |
| M30 × 3.5 | 30.00 | 29.67 | 45.00 | 44.42 | 30.00 | 29.67 | 3.00 | 22.0 | ... | 15.00 | 33.4 |
| M36 × 4 | 36.00 | 35.61 | 54.00 | 53.37 | 36.00 | 35.64 | 3.60 | 27.0 | ... | 18.00 | 39.4 |
| M42 × 4.5 | 42.00 | 41.61 | 63.00 | 62.31 | 42.00 | 41.61 | 4.20 | 32.0 | ... | 21.00 | 45.6 |
| M48 × 5 | 48.00 | 47.61 | 72.00 | 71.27 | 48.00 | 47.58 | 4.80 | 36.0 | ... | 24.00 | 52.6 |

^a See also Table 2.

^b The M14 × 2 size is not recommended for use in new designs.

All dimensions are in millimeters *L_G* is grip length and *L_B* is body length. For length of complete thread, For additional manufacturing and acceptance specifications, see ANSI/ASME B18.3.1M.

**Table 5. American National Standard Hexagon and Spline
Socket Set Screws ANSI/ASME B18.3-1998**

| | | Socket Size | | Cup and Flat Point Diameters | | Half Dog Point | | Oval Point Radius | Min. Key Engagement Depth | | Lgth. Limit for Angle |
|--------------------------------------|--------|----------------|-------|------------------------------|-------|----------------|---------|-------------------|---------------------------|-------|-----------------------|
| Nominal Size or Basic Screw Diameter | Hex. | Spl. | Nom. | Nom. | Max. | Min. | Dia. | Lgth. | Basic | Hex. | Spl. |
| | J | M | C | P | Q | R | T_H^a | T_S^a | Y ^b | | |
| | 0 | 0.0600 | 0.028 | 0.033 | 0.033 | 0.027 | 0.040 | 0.017 | 0.045 | 0.050 | 0.026 |
| 1 | 0.0730 | 0.035 | 0.033 | 0.040 | 0.033 | 0.049 | 0.021 | 0.055 | 0.060 | 0.035 | 0.09 |
| 2 | 0.0860 | 0.035 | 0.048 | 0.047 | 0.039 | 0.057 | 0.024 | 0.064 | 0.060 | 0.040 | 0.13 |
| 3 | 0.0990 | 0.050 | 0.048 | 0.054 | 0.045 | 0.066 | 0.027 | 0.074 | 0.070 | 0.040 | 0.13 |
| 4 | 0.1120 | 0.050 | 0.060 | 0.061 | 0.051 | 0.075 | 0.030 | 0.084 | 0.070 | 0.045 | 0.19 |
| 5 | 0.1250 | $\frac{1}{16}$ | 0.072 | 0.067 | 0.057 | 0.083 | 0.033 | 0.094 | 0.080 | 0.055 | 0.19 |
| 6 | 0.1380 | $\frac{1}{16}$ | 0.072 | 0.074 | 0.064 | 0.092 | 0.038 | 0.104 | 0.080 | 0.055 | 0.19 |
| 8 | 0.1640 | $\frac{5}{64}$ | 0.096 | 0.087 | 0.076 | 0.109 | 0.043 | 0.123 | 0.090 | 0.080 | 0.25 |
| 10 | 0.1900 | $\frac{3}{32}$ | 0.111 | 0.102 | 0.088 | 0.127 | 0.049 | 0.142 | 0.100 | 0.080 | 0.25 |
| $\frac{1}{4}$ | 0.2500 | $\frac{1}{8}$ | 0.145 | 0.132 | 0.118 | 0.156 | 0.067 | 0.188 | 0.125 | 0.125 | 0.31 |
| $\frac{5}{16}$ | 0.3125 | $\frac{5}{32}$ | 0.183 | 0.172 | 0.156 | 0.203 | 0.082 | 0.234 | 0.156 | 0.156 | 0.38 |
| $\frac{3}{8}$ | 0.3750 | $\frac{3}{16}$ | 0.216 | 0.212 | 0.194 | 0.250 | 0.099 | 0.281 | 0.188 | 0.188 | 0.44 |
| $\frac{7}{16}$ | 0.4375 | $\frac{7}{32}$ | 0.251 | 0.252 | 0.232 | 0.297 | 0.114 | 0.328 | 0.219 | 0.219 | 0.50 |
| $\frac{1}{2}$ | 0.5000 | $\frac{1}{4}$ | 0.291 | 0.291 | 0.270 | 0.344 | 0.130 | 0.375 | 0.250 | 0.250 | 0.57 |
| $\frac{5}{8}$ | 0.6250 | $\frac{5}{16}$ | 0.372 | 0.371 | 0.347 | 0.469 | 0.164 | 0.469 | 0.312 | 0.312 | 0.75 |
| $\frac{3}{4}$ | 0.7500 | $\frac{3}{8}$ | 0.454 | 0.450 | 0.425 | 0.562 | 0.196 | 0.562 | 0.375 | 0.375 | 0.88 |
| $\frac{7}{8}$ | 0.8750 | $\frac{1}{2}$ | 0.595 | 0.530 | 0.502 | 0.656 | 0.227 | 0.656 | 0.500 | 0.500 | 1.00 |
| 1 | 1.0000 | $\frac{9}{16}$ | ... | 0.609 | 0.579 | 0.750 | 0.260 | 0.750 | 0.562 | ... | 1.13 |
| $1\frac{1}{8}$ | 1.1250 | $\frac{1}{16}$ | ... | 0.689 | 0.655 | 0.844 | 0.291 | 0.844 | 0.562 | ... | 1.25 |
| $1\frac{1}{4}$ | 1.2500 | $\frac{5}{8}$ | ... | 0.767 | 0.733 | 0.938 | 0.323 | 0.938 | 0.625 | ... | 1.50 |
| $1\frac{3}{8}$ | 1.3750 | $\frac{5}{8}$ | ... | 0.848 | 0.808 | 1.031 | 0.354 | 1.031 | 0.625 | ... | 1.63 |
| $1\frac{1}{2}$ | 1.5000 | $\frac{3}{4}$ | ... | 0.926 | 0.886 | 1.125 | 0.385 | 1.125 | 0.750 | ... | 1.75 |
| $1\frac{3}{4}$ | 1.7500 | 1 | ... | 1.086 | 1.039 | 1.312 | 0.448 | 1.321 | 1.000 | ... | 2.00 |
| 2 | 2.0000 | 1 | ... | 1.244 | 1.193 | 1.500 | 0.510 | 1.500 | 1.000 | ... | 2.25 |

^a Reference should be made to the Standard for shortest optimum nominal lengths to which the minimum key engagement depths T_H and T_S apply.

^b Cone point angle Y is 90 degrees plus or minus 2 degrees for these nominal lengths or longer and 118 degrees plus or minus 2 degrees for shorter nominal lengths.

All dimensions are in inches. The thread conforms to the Unified Standard, Class 3A, UNC and UNF series. The socket depth T is included in the Standard and some are shown here. The nominal length L of all socket type set screws is the total or overall length. For nominal screw lengths of $\frac{1}{16}$ through $\frac{5}{16}$ inch (0 through 3 sizes incl.) the standard length increment is 0.06 inch; for lengths $\frac{1}{8}$ through 1 inch the increment is $\frac{1}{8}$ inch; for lengths 1 through 2 inches the increment is $\frac{1}{4}$ inch; for lengths 2 through 6 inches the increment is $\frac{1}{2}$ inch; for lengths 6 inches and longer the increment is 1 inch.

Length Tolerance: The allowable tolerance on length L for all set screws of the socket type is ± 0.01 inch for set screws up to $\frac{5}{8}$ inch long; ± 0.02 inch for screws over $\frac{5}{8}$ to 2 inches long; ± 0.03 inch for screws over 2 to 6 inches long and ± 0.06 inch for screws over 6 inches long. For manufacturing details, including materials, not shown, see American National Standard ANSI/ASME B18.3-1998.

Table 6. Drill and Counterbore Sizes For Socket Head Cap Screws (1960 Series)

| Nominal Size or Basic Screw Diameter | Nominal Drill Size | | | | Counterbore Diameter | Countersink Diameter ^a | | |
|--------------------------------------|---------------------------|--------------|---------------------------|--------------|----------------------|-----------------------------------|--|--|
| | Close Fit ^b | | Normal Fit ^c | | | | | |
| | Number or Fractional Size | Decimal Size | Number or Fractional Size | Decimal Size | | | | |
| | | A | | | B | C | | |
| 0 | 0.0600 | 51 | 0.067 | 49 | 0.073 | 1/8 | | |
| 1 | 0.0730 | 46 | 0.081 | 43 | 5/32 | 0.087 | | |
| 2 | 0.0860 | 3/32 | 0.094 | 36 | 3/16 | 0.102 | | |
| 3 | 0.0990 | 36 | 0.106 | 31 | 7/32 | 0.115 | | |
| 4 | 0.1120 | 1/8 | 0.125 | 29 | 1/4 | 0.130 | | |
| 5 | 0.1250 | 5/64 | 0.141 | 23 | 1/4 | 0.145 | | |
| 6 | 0.1380 | 23 | 0.154 | 18 | 5/32 | 0.158 | | |
| 8 | 0.1640 | 15 | 0.180 | 10 | 5/16 | 0.188 | | |
| 10 | 0.1900 | 5 | 0.206 | 2 | 3/8 | 0.218 | | |
| 1/4 | 0.2500 | 17/64 | 0.266 | 9/32 | 7/16 | 0.278 | | |
| 5/16 | 0.3125 | 21/64 | 0.328 | 11/32 | 17/32 | 0.346 | | |
| 3/8 | 0.3750 | 25/64 | 0.391 | 13/32 | 406 | 5/8 | | |
| 7/16 | 0.4375 | 29/64 | 0.453 | 15/32 | 469 | 23/32 | | |
| 1/2 | 0.5000 | 33/64 | 0.516 | 17/32 | 0.531 | 13/16 | | |
| 5/8 | 0.6250 | 41/64 | 0.641 | 21/32 | 0.656 | 1 | | |
| 3/4 | 0.7500 | 49/64 | 0.766 | 25/32 | 0.781 | 13/16 | | |
| 7/8 | 0.8750 | 57/64 | 0.891 | 29/32 | 0.906 | 15/8 | | |
| 1 | 1.0000 | 11/64 | 1.016 | 11/32 | 1.031 | 15/8 | | |
| 1 1/4 | 1.2500 | 19/32 | 1.281 | 1 5/16 | 1.312 | 2 | | |
| 1 1/2 | 1.5000 | 117/32 | 1.531 | 1 1/16 | 1.562 | 23/8 | | |
| 1 3/4 | 1.7500 | 125/32 | 1.781 | 113/16 | 1.812 | 23/4 | | |
| 2 | 2.0000 | 21/32 | 2.031 | 21/16 | 2.062 | 31/8 | | |

^a *Countersink:* It is considered good practice to countersink or break the edges of holes which are smaller than $(D_{\text{Max}} + 2F_{\text{Max}})$ in parts having a hardness which approaches, equals or exceeds the screw hardness. If such holes are not countersunk, the heads of screws may not seat properly or the sharp edges on holes may deform the fillets on screws thereby making them susceptible to fatigue in applications involving dynamic loading. The countersink or corner relief, however, should not be larger than is necessary to insure that the fillet on the screw is cleared.

^b *Close Fit:* The close fit is normally limited to holes for those lengths of screws which are threaded to the head in assemblies where only one screw is to be used or where two or more screws are to be used and the mating holes are to be produced either at assembly or by matched and coordinated tooling.

^c *Normal Fit:* The normal fit is intended for screws of relatively long length or for assemblies involving two or more screws where the mating holes are to be produced by conventional tolerancing methods. It provides for the maximum allowable eccentricity of the longest standard screws and for certain variations in the parts to be fastened, such as: deviations in hole straightness, angularity between the axis of the tapped hole and that of the hole for the shank, differences in center distances of the mating holes, etc.

All dimensions in inches.

Source: Appendix to American National Standard ANSI/ASME B18.3-1998.

Table 7. American National Standard Hexagon and Spline Socket Flat Countersunk Head Cap Screws ANSI/ASME B18.3-1998

| Nominal Size | Body Diam. | | Head Diameter | | Head Height Reference | Spline Socket Size | Hexagon Socket Size | Key Engagement |
|----------------|------------|--------|------------------------|-----------|-----------------------|--------------------|---------------------|----------------|
| | | | Theoretical Sharp Max. | Abs. Min. | | | Nom. | Min. |
| | D | | A | H | | | J | T |
| | Max. | Min. | | | | | | |
| 0 | 0.0600 | 0.0568 | 0.138 | 0.117 | 0.044 | 0.048 | 0.035 | 0.025 |
| 1 | 0.0730 | 0.0695 | 0.168 | 0.143 | 0.054 | 0.060 | 0.050 | 0.031 |
| 2 | 0.0860 | 0.0822 | 0.197 | 0.168 | 0.064 | 0.060 | 0.050 | 0.038 |
| 3 | 0.0990 | 0.0949 | 0.226 | 0.193 | 0.073 | 0.072 | $\frac{1}{16}$ | 0.044 |
| 4 | 0.1120 | 0.1075 | 0.255 | 0.218 | 0.083 | 0.072 | $\frac{1}{16}$ | 0.055 |
| 5 | 0.1250 | 0.1202 | 0.281 | 0.240 | 0.090 | 0.096 | $\frac{5}{64}$ | 0.061 |
| 6 | 0.1380 | 0.1329 | 0.307 | 0.263 | 0.097 | 0.096 | $\frac{5}{64}$ | 0.066 |
| 8 | 0.1640 | 0.1585 | 0.359 | 0.311 | 0.112 | 0.111 | $\frac{3}{32}$ | 0.076 |
| 10 | 0.1900 | 0.1840 | 0.411 | 0.359 | 0.127 | 0.145 | $\frac{1}{8}$ | 0.087 |
| $\frac{1}{4}$ | 0.2500 | 0.2435 | 0.531 | 0.480 | 0.161 | 0.183 | $\frac{5}{32}$ | 0.111 |
| $\frac{5}{16}$ | 0.3125 | 0.3053 | 0.656 | 0.600 | 0.198 | 0.216 | $\frac{3}{16}$ | 0.135 |
| $\frac{3}{8}$ | 0.3750 | 0.3678 | 0.781 | 0.720 | 0.234 | 0.251 | $\frac{7}{32}$ | 0.159 |
| $\frac{7}{16}$ | 0.4375 | 0.4294 | 0.844 | 0.781 | 0.234 | 0.291 | $\frac{1}{4}$ | 0.159 |
| $\frac{1}{2}$ | 0.5000 | 0.4919 | 0.938 | 0.872 | 0.251 | 0.372 | $\frac{5}{16}$ | 0.172 |
| $\frac{5}{8}$ | 0.6250 | 0.6163 | 1.188 | 1.112 | 0.324 | 0.454 | $\frac{3}{8}$ | 0.220 |
| $\frac{3}{4}$ | 0.7500 | 0.7406 | 1.438 | 1.355 | 0.396 | 0.454 | $\frac{1}{2}$ | 0.220 |
| $\frac{7}{8}$ | 0.8750 | 0.8647 | 1.688 | 1.604 | 0.468 | ... | $\frac{1}{16}$ | 0.248 |
| 1 | 1.0000 | 0.9886 | 1.938 | 1.841 | 0.540 | ... | $\frac{5}{8}$ | 0.297 |
| $1\frac{1}{8}$ | 1.1250 | 1.1086 | 2.188 | 2.079 | 0.611 | ... | $\frac{3}{4}$ | 0.325 |
| $1\frac{1}{4}$ | 1.2500 | 1.2336 | 2.438 | 2.316 | 0.683 | ... | $\frac{7}{8}$ | 0.358 |
| $1\frac{3}{8}$ | 1.3750 | 1.3568 | 2.688 | 2.553 | 0.755 | ... | $\frac{7}{8}$ | 0.402 |
| $1\frac{1}{2}$ | 1.5000 | 1.4818 | 2.938 | 2.791 | 0.827 | ... | 1 | 0.435 |

All dimensions in inches.

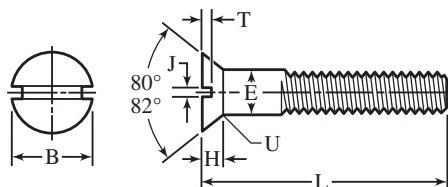
The body of the screw is the unthreaded cylindrical portion of the shank where not threaded to the head; the shank being the portion of the screw from the point of juncture of the conical bearing surface and the body to the flat of the point. The length of thread L_T is the distance measured from the extreme point to the last complete (full form) thread.

Standard length increments of No. 0 through 1-inch sizes are as follows: $\frac{1}{16}$ inch for nominal screw lengths of $\frac{1}{8}$ through $\frac{1}{4}$ inch; $\frac{1}{8}$ inch for lengths of $\frac{1}{4}$ through 1 inch; $\frac{1}{4}$ inch for lengths of 1 inch through $3\frac{1}{2}$ inches; $\frac{1}{2}$ inch for lengths of $3\frac{1}{2}$ through 7 inches; and 1 inch for lengths of 7 through 10 inches, incl. For screw sizes over 1 inch, length increments are: $\frac{1}{2}$ inch for nominal screw lengths of 1 inch through 7 inches; 1 inch for lengths of 7 through 10 inches; and 2 inches for lengths over 10 inches.

Threads shall be Unified external threads with radius root; Class 3A UNRC and UNRF series for sizes No. 0 through 1 inch and Class 2A UNRC and UNRF series for sizes over 1 inch to $1\frac{1}{2}$ inches, incl.

For manufacturing details not shown, including materials, see American National Standard ANSI/ASME B18.3-1998 .

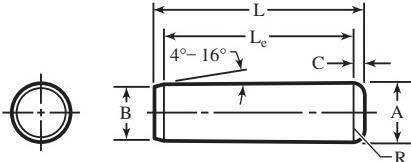
Table 8. American National Standard Slotted Flat Countersunk Head Cap Screws ANSI B18.6.2-1972, R1998



| Nominal Size ^a or Basic Screw Diam. | | Body Diam., E | | Head Dia., A | | Head Hgt., H | Slot Width, J | | Slot Depth, T | | Fillet Rad., U |
|--|--------|---------------|--------|--------------|---------------------|--------------|---------------|-------|---------------|-------|----------------|
| | | | | Edge Sharp | Edge Rnd'd. or Flat | | Max. | Min. | Ref. | Max. | |
| | | Max. | Min. | Max. | Min. | | Max. | Min. | Max. | Min. | Max. |
| 1/4 | 0.2500 | 0.2500 | 0.2450 | 0.500 | 0.452 | 0.140 | 0.075 | 0.064 | 0.068 | 0.045 | 0.100 |
| 5/16 | 0.3125 | 0.3125 | 0.3070 | 0.625 | 0.567 | 0.177 | 0.084 | 0.072 | 0.086 | 0.057 | 0.125 |
| 3/8 | 0.3750 | 0.3750 | 0.3690 | 0.750 | 0.682 | 0.210 | 0.094 | 0.081 | 0.103 | 0.068 | 0.150 |
| 7/16 | 0.4375 | 0.4375 | 0.4310 | 0.812 | 0.736 | 0.210 | 0.094 | 0.081 | 0.103 | 0.068 | 0.175 |
| 1/2 | 0.5000 | 0.5000 | 0.4930 | 0.875 | 0.791 | 0.210 | 0.106 | 0.091 | 0.103 | 0.068 | 0.200 |
| 9/16 | 0.5625 | 0.5625 | 0.5550 | 1.000 | 0.906 | 0.244 | 0.118 | 0.102 | 0.120 | 0.080 | 0.225 |
| 5/8 | 0.6250 | 0.6250 | 0.6170 | 1.125 | 1.020 | 0.281 | 0.133 | 0.116 | 0.137 | 0.091 | 0.250 |
| 3/4 | 0.7500 | 0.7500 | 0.7420 | 1.375 | 1.251 | 0.352 | 0.149 | 0.131 | 0.171 | 0.115 | 0.300 |
| 7/8 | 0.8750 | 0.8750 | 0.8660 | 1.625 | 1.480 | 0.423 | 0.167 | 0.147 | 0.206 | 0.138 | 0.350 |
| 1 | 1.0000 | 1.0000 | 0.9900 | 1.875 | 1.711 | 0.494 | 0.188 | 0.166 | 0.240 | 0.162 | 0.400 |
| 1 1/8 | 1.1250 | 1.1250 | 1.1140 | 2.062 | 1.880 | 0.529 | 0.196 | 0.178 | 0.257 | 0.173 | 0.450 |
| 1 1/4 | 1.2500 | 1.2500 | 1.2390 | 2.312 | 2.110 | 0.600 | 0.211 | 0.193 | 0.291 | 0.197 | 0.500 |
| 1 3/8 | 1.3750 | 1.3750 | 1.3630 | 2.562 | 2.340 | 0.665 | 0.226 | 0.208 | 0.326 | 0.220 | 0.550 |
| 1 1/2 | 1.5000 | 1.5000 | 1.4880 | 2.812 | 2.570 | 0.742 | 0.258 | 0.240 | 0.360 | 0.244 | 0.600 |

^a When specifying a nominal size in decimals, the zero preceding the decimal point is omitted as is any zero in the fourth decimal place.

All dimensions are in inches. *Threads:* Threads are Unified Standard Class 2A; UNC, UNF and 8 UN Series or UNRC, UNRF, and 8 UNR Series.

Table 9. American National Standard Hardened Ground Machine Dowel Pins ANSI B18.8.2-2000


| Nominal Size ^a or Nominal Pin Diameter | Pin Diameter, A | | | | | | Point Diameter, B | Crown Height, C Max | Crown Radius, R Min | Range of Preferred Lengths, ^b L | Single Shear Load for Carbon or Alloy Steel Calculated lb | Suggested Hole Diameter ^c | | | |
|--|-------------------------|--------|--------|-------------------------|--------|--------|----------------------|---------------------------|---------------------------|---|---|---|---------|--------|--------|
| | Standard Series Pins | | | Oversize Series Pins | | | | | | | | | | | |
| | Basic | Max | Min | Basic | Max | Min | Max | Min | Max | Min | Max | Min | | | |
| 1/16 | 0.0625 | 0.0627 | 0.0628 | 0.0626 | 0.0635 | 0.0636 | 0.058 | 0.048 | 0.020 | 0.008 | 3/16-3/4 | 400 | 0.0625 | 0.0620 | |
| 5/64 ^d | 0.0781 | 0.0783 | 0.0784 | 0.0782 | 0.0791 | 0.0792 | 0.074 | 0.064 | 0.026 | 0.010 | ... | 620 | 0.0781 | 0.0776 | |
| 3/32 | 0.0938 | 0.0940 | 0.0941 | 0.0939 | 0.0948 | 0.0949 | 0.089 | 0.079 | 0.031 | 0.012 | 3/16-1 | 900 | 0.0937 | 0.0932 | |
| 1/8 | 0.1250 | 0.1252 | 0.1253 | 0.1251 | 0.1260 | 0.1261 | 0.1259 | 0.120 | 0.110 | 0.041 | 0.016 | 3/8-2 | 1600 | 0.1250 | 0.1245 |
| 5/32 ^d | 0.1562 | 0.1564 | 0.1565 | 0.1563 | 0.1572 | 0.1573 | 0.1571 | 0.150 | 0.140 | 0.052 | 0.020 | ... | 2500 | 0.1562 | 0.1557 |
| 3/16 | 0.1875 | 0.1877 | 0.1878 | 0.1876 | 0.1885 | 0.1886 | 0.1884 | 0.180 | 0.170 | 0.062 | 0.023 | 1/2-2 | 3600 | 0.1875 | 0.1870 |
| 1/4 | 0.2500 | 0.2502 | 0.2503 | 0.2501 | 0.2510 | 0.2511 | 0.2509 | 0.240 | 0.230 | 0.083 | 0.031 | 1/2-2 1/2 | 6,400 | 0.2500 | 0.2495 |
| 5/16 | 0.3125 | 0.3127 | 0.3128 | 0.3126 | 0.3135 | 0.3136 | 0.3134 | 0.302 | 0.290 | 0.104 | 0.039 | 1/2-2 1/2 | 10,000 | 0.3125 | 0.3120 |
| 3/8 | 0.3750 | 0.3752 | 0.3753 | 0.3751 | 0.3760 | 0.3761 | 0.3759 | 0.365 | 0.350 | 0.125 | 0.047 | 1/2-3 | 14,350 | 0.3750 | 0.3745 |
| 7/16 | 0.4375 | 0.4377 | 0.4378 | 0.4376 | 0.4385 | 0.4386 | 0.4384 | 0.424 | 0.409 | 0.146 | 0.055 | 7/8-3 | 19,550 | 0.4375 | 0.4370 |
| 1/2 | 0.5000 | 0.5002 | 0.5003 | 0.5001 | 0.5010 | 0.5011 | 0.5009 | 0.486 | 0.471 | 0.167 | 0.063 | 3/4, 1-4 | 25,500 | 0.5000 | 0.4995 |
| 5/8 | 0.6250 | 0.6252 | 0.6253 | 0.6251 | 0.6260 | 0.6261 | 0.6259 | 0.611 | 0.595 | 0.208 | 0.078 | 1 1/4-5 | 39,900 | 0.6250 | 0.6245 |
| 3/4 | 0.7500 | 0.7502 | 0.7503 | 0.7501 | 0.7510 | 0.7511 | 0.7509 | 0.735 | 0.715 | 0.250 | 0.094 | 1 1/2-6 | 57,000 | 0.7500 | 0.7495 |
| 7/8 | 0.8750 | 0.8752 | 0.8753 | 0.8751 | 0.8760 | 0.8761 | 0.8759 | 0.860 | 0.840 | 0.293 | 0.109 | 2 1/2-6 | 78,000 | 0.8750 | 0.8745 |
| 1 | 1.0000 | 1.0002 | 1.0003 | 1.0001 | 1.0010 | 1.0011 | 1.0009 | 0.980 | 0.960 | 0.333 | 0.125 | 2,2 1/2-5,6 | 102,000 | 1.0000 | 0.9995 |

^a In the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal diameter as basic size. Here, they are included.

^b Lengths increase in 1/16-inch steps up to 3/8 inch, in 1/8-inch steps from 3/8 inch to 1 inch, in 1/4-inch steps from 1 inch to 2 1/2 inches, and in 1/2-inch steps above 2 1/2 inches.

Tolerance on length is ± 0.010 inch.

^c These hole sizes have been commonly used for press fitting Standard Series machine dowel pins into materials such as mild steels and cast iron. In soft materials such as aluminum or zinc die castings, hole size limits are usually decreased by 0.0005 inch to increase the press fit.

^d Nonpreferred sizes, not recommended for use in new designs.

All dimensions are in inches.

American National Standard Hardened Ground Production Dowel Pins.—Hardened ground production dowel pins have basic diameters that are 0.0002 inch over the nominal pin diameter.

Preferred Lengths and Sizes: The preferred lengths and sizes of these pins are given in Table 10. Other sizes and lengths are produced as required by the purchaser.

Table 10. American National Standard Hardened Ground Production Dowel Pins ANSI B18.8.2-2000

| Nominal Size ^a or Nominal Pin Diameter | Pin Diameter, A | | | Corner Radius, R | | Range of Preferred Lengths, ^b L | Single Shear Load, Carbon Steel | Suggested Hole Diameter ^c | |
|---|-----------------|--------|--------|------------------|-------|--|---------------------------------|--------------------------------------|--------|
| | Basic | Max | Min | Max | Min | | | Max | Min |
| 1/16 0.0625 | 0.0627 | 0.0628 | 0.0626 | 0.020 | 0.010 | 3/16-1 | 395 | 0.0625 | 0.0620 |
| 5/32 0.0938 | 0.0939 | 0.0940 | 0.0938 | 0.020 | 0.010 | 3/16-2 | 700 | 0.0937 | 0.0932 |
| 7/64 0.1094 | 0.1095 | 0.1096 | 0.1094 | 0.020 | 0.010 | 3/16-2 | 950 | 0.1094 | 0.1089 |
| 1/8 0.1250 | 0.1252 | 0.1253 | 0.1251 | 0.020 | 0.010 | 3/16-2 | 1300 | 0.1250 | 0.1245 |
| 9/32 0.1562 | 0.1564 | 0.1565 | 0.1563 | 0.020 | 0.010 | 3/16-2 | 2050 | 0.1562 | 0.1557 |
| 5/16 0.1875 | 0.1877 | 0.1878 | 0.1876 | 0.020 | 0.010 | 3/16-2 | 2950 | 0.1875 | 0.1870 |
| 7/32 0.2188 | 0.2189 | 0.2190 | 0.2188 | 0.020 | 0.010 | 1/4-2 | 3800 | 0.2188 | 0.2183 |
| 1/4 0.2500 | 0.2502 | 0.2503 | 0.2501 | 0.020 | 0.010 | 1/4-1 1/2, 1 3/4, 2-2 1/2 | 5,000 | 0.2500 | 0.2495 |
| 9/16 0.3125 | 0.3127 | 0.3128 | 0.3126 | 0.020 | 0.010 | 5/16-1 1/2, 1 3/4, 2-2 1/2 | 8,000 | 0.3125 | 0.3120 |
| 5/8 0.3750 | 0.3752 | 0.3753 | 0.3751 | 0.020 | 0.010 | 3/8-1 1/2, 1 3/4, 2-3 | 11,500 | 0.3750 | 0.3745 |

^a In the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal pin size in decimals. Here, they are included.

^b Lengths increase in 1/16-inch steps up to 1 inch, in 1/8-inch steps from 1 inch to 2 inches and then are 2 1/4, 2 1/2, and 3 inches.

^c These hole sizes have been commonly used for press fitting production dowel pins into materials such as mild steels and cast iron. In soft materials such as aluminum or zinc die castings, hole size limits are usually decreased by 0.0005 inch to increase the press fit.

All dimensions are in inches.

Size: These pins have basic diameters that are 0.0002 inch over the nominal pin diameter. The diameter shall be ground, or ground and lapped, to within ± 0.0001 inch of the basic diameter as specified in Table 10.

Roundness, Straightness, and Surface Roughness: These standard pins shall conform to true round within 0.0001 inch; straightness over that portion of the length not affected by the rounded ends, within an accumulative total of 0.005 inch per inch of length for nominal lengths up to 4 inches, and within 0.002 inch total for all nominal lengths over 4 inches; roughness shall not exceed 8 microinches ($\mu\text{in.}$) over the cylindrical portion of the pin, nor over 125 $\mu\text{in.}$ on all other surfaces.

Designation: These pins are designated by the following data in the sequence shown: Product name (noun first), nominal pin diameter (fraction or decimal equivalent), length (fraction or decimal equivalent), material, and protective finish, if required.

Examples: Pins, Hardened Ground Production Dowel, $1/8 \times 5/16$, Steel, Phosphate Coated Pins, Hardened Ground Production Dowel, 0.375×1.500 , Steel

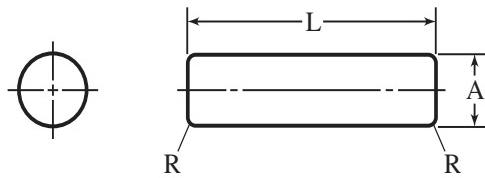


Table 11. American National Standard Chamfered and Square End Straight Pins
ANSI B18.8.2-2000

| CHAMFERED STRAIGHT PIN | | | | | | | | SQUARE END STRAIGHT PIN | | | |
|---|-----------------|--------|-------------------|-------|---|-----------------|-------|-------------------------|--------|-------|-------|
| Nominal Size ^a or Basic Pin Diameter | Pin Diameter, A | | Chamfer Length, C | | Nominal Size ^a or Basic Pin Diameter | Pin Diameter, A | | Chamfer Length, C | | | |
| | Max | Min | Max | Min | | Max | Min | Max | Min | | |
| $\frac{1}{16}$ | 0.062 | 0.0625 | 0.0605 | 0.025 | 0.005 | $\frac{5}{16}$ | 0.312 | 0.3125 | 0.3105 | 0.040 | 0.020 |
| $\frac{3}{32}$ | 0.094 | 0.0937 | 0.0917 | 0.025 | 0.00 | $\frac{3}{8}$ | 0.375 | 0.3750 | 0.3730 | 0.040 | 0.020 |
| $\frac{7}{64}$ ^b | 0.109 | 0.1094 | 0.1074 | 0.025 | 0.005 | $\frac{7}{16}$ | 0.438 | 0.4375 | 0.4355 | 0.040 | 0.020 |
| $\frac{1}{8}$ | 0.125 | 0.1250 | 0.1230 | 0.025 | 0.005 | $\frac{1}{2}$ | 0.500 | 0.5000 | 0.4980 | 0.040 | 0.020 |
| $\frac{5}{32}$ | 0.156 | 0.1562 | 0.1542 | 0.025 | 0.005 | $\frac{5}{8}$ | 0.625 | 0.6250 | 0.6230 | 0.055 | 0.035 |
| $\frac{3}{16}$ | 0.188 | 0.1875 | 0.1855 | 0.025 | 0.005 | $\frac{3}{4}$ | 0.750 | 0.7500 | 0.7480 | 0.055 | 0.035 |
| $\frac{7}{32}$ | 0.219 | 0.2187 | 0.2167 | 0.025 | 0.005 | $\frac{7}{8}$ | 0.875 | 0.8750 | 0.8730 | 0.055 | 0.035 |
| $\frac{1}{4}$ | 0.250 | 0.2500 | 0.2480 | 0.025 | 0.005 | 1 | 1.000 | 1.0000 | 0.9980 | 0.055 | 0.035 |

^aIn the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal size in decimals. Here, they are included.

^bNonpreferred sizes, not recommended for use in new designs.

All dimensions are in inches.

American National Standard Straight Pins.—The diameter of both chamfered and square end straight pins is that of the commercial wire or rod from which the pins are made. The tolerances shown in Table 11 are applicable to carbon steel and some deviations in the diameter limits may be necessary for pins made from other materials.

Length Increments: Lengths are as specified by the purchaser; however, it is recommended that nominal pin lengths be limited to increments of not less than 0.062 inch.

Material: Straight pins are normally made from cold drawn steel wire or rod having a maximum carbon content of 0.28 per cent having a maximum hardness of R_c 32. Where required, pins may also be made from corrosion resistant steel, brass, or other metals.

Designation: Straight pins are designated by the following data, in the sequence shown: Product name (noun first), nominal size (fraction or decimal equivalent), material, and protective finish, if required.

Examples: Pin, Chamfered Straight, $\frac{1}{8} \times 1.500$, Steel

Pin, Square End Straight, 0.250 × 2.250, Steel, Zinc Plated

American National Standard Taper Pins.—Taper pins have a uniform taper over the pin length with both ends crowned. Most sizes are supplied in commercial and precision classes, the latter having generally tighter tolerances and being more closely controlled in manufacture.

Diameters: The major diameter of both commercial and precision classes of pins is the diameter of the large end and is the basis for pin size. The diameter at the small end is computed by multiplying the nominal length of the pin by the factor 0.02083 and subtracting the result from the basic pin diameter. See also Table 12.

Taper: The taper on commercial class pins is 0.250 ± 0.006 inch per foot and on the precision class pins is 0.250 ± 0.004 inch per foot of length.

Materials: Unless otherwise specified, taper pins are made from AISI 1211 steel or cold drawn AISI 1212 or 1213 steel or equivalents, and no mechanical property requirements apply.

Hole Sizes: Under most circumstances, holes for taper pins require taper reaming. Sizes and lengths of taper pins for which standard reamers are available are given in Table 12. Drilling specifications for taper pins are given below.

Table 12. American National Standard Taper Pins
ANSI B18.8.2-1978, R2000

| Pin Size Number and Basic Pin Diameter ^a | Major Diameter (Large End), A | | | | End Crown Radius, R | | Range of Lengths ^b , L | |
|---|-------------------------------|--------|-----------------|--------|---------------------|-------|-----------------------------------|--------------|
| | Commercial Class | | Precision Class | | Max | Min | Stand. Reamer Avail. ^c | Other |
| | Max | Min | Max | Min | | | | |
| 1/8 0.0625 | 0.0638 | 0.0618 | 0.0635 | 0.0625 | 0.072 | 0.052 | ... | 1/4-1 |
| 3/16 0.0780 | 0.0793 | 0.0773 | 0.0790 | 0.0780 | 0.088 | 0.068 | ... | 1/4-1 1/2 |
| 7/32 0.0940 | 0.0953 | 0.0933 | 0.0950 | 0.0940 | 0.104 | 0.084 | 1/4-1 | 1 1/4, 1 1/2 |
| 1/4 0.1090 | 0.1103 | 0.1083 | 0.1100 | 0.1090 | 0.119 | 0.099 | 1/4-1 | 1 1/4-2 |
| 5/32 0.1250 | 0.1263 | 0.1243 | 0.1260 | 0.1250 | 0.135 | 0.115 | 1/4-1 | 1 1/4-2 |
| 3/16 0.1410 | 0.1423 | 0.1403 | 0.1420 | 0.1410 | 0.151 | 0.131 | 1/2-1 1/4 | 1 1/2-2 1/2 |
| 0 0.1560 | 0.1573 | 0.1553 | 0.1570 | 0.1560 | 0.166 | 0.146 | 1/2-1 1/4 | 1 1/2-3 |
| 1 0.1720 | 0.1733 | 0.1713 | 0.1730 | 0.1720 | 0.182 | 0.162 | 3/4-1 1/4 | 1 1/2-3 |
| 2 0.1930 | 0.1943 | 0.1923 | 0.1940 | 0.1930 | 0.203 | 0.183 | 3/4-1 1/2 | 1 3/4-3 |
| 3 0.2190 | 0.2203 | 0.2183 | 0.2200 | 0.2190 | 0.229 | 0.209 | 3/4-1 3/4 | 2-4 |
| 4 0.2500 | 0.2513 | 0.2493 | 0.2510 | 0.2500 | 0.260 | 0.240 | 3/4-2 | 2 1/4-4 |
| 5 0.2890 | 0.2903 | 0.2883 | 0.2900 | 0.2890 | 0.299 | 0.279 | 1-2 1/2 | 2 3/4-6 |
| 6 0.3410 | 0.3423 | 0.3403 | 0.3420 | 0.3410 | 0.351 | 0.331 | 1 1/4-3 | 3 1/4-6 |
| 7 0.4090 | 0.4103 | 0.4083 | 0.4100 | 0.4090 | 0.419 | 0.399 | 1 1/4-3 3/4 | 4-8 |
| 8 0.4920 | 0.4933 | 0.4913 | 0.4930 | 0.4920 | 0.502 | 0.482 | 1 1/4-4 1/2 | 4 3/4-8 |
| 9 0.5910 | 0.5923 | 0.5903 | 0.5920 | 0.5910 | 0.601 | 0.581 | 1 1/4-5 1/4 | 5 1/2-8 |
| 10 0.7060 | 0.7073 | 0.7053 | 0.7070 | 0.7060 | 0.716 | 0.696 | 1 1/2-6 | 6 1/4-8 |
| 11 0.8600 | 0.8613 | 0.8593 | ... | ... | 0.870 | 0.850 | ... | 2-8 |
| 12 1.0320 | 1.0333 | 1.0313 | ... | ... | 1.042 | 1.022 | ... | 2-9 |
| 13 1.2410 | 1.2423 | 1.2403 | ... | ... | 1.251 | 1.231 | ... | 3-11 |
| 14 1.5210 | 1.5223 | 1.5203 | ... | ... | 1.533 | 1.513 | ... | 3-13 |

^aIn the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal pin size in decimals. Here, they are included.

^bLengths increase in 1/8-inch steps up to 1 inch and in 1/4-inch steps above 1 inch.

^cStandard reamers are available for pin lengths in this column.

All dimensions are in inches.

For nominal diameters, B, see Table 12.

Designation: Taper pins are designated by the following data in the sequence shown: Product name (noun first), class, size number (or decimal equivalent), length (fraction or three-place decimal equivalent), material, and protective finish, if required.

Examples: Pin, Taper (Commercial Class) No. 0 × 3/4, Steel

Pin, Taper (Precision Class) 0.219 × 1.750, Steel, Zinc Plated

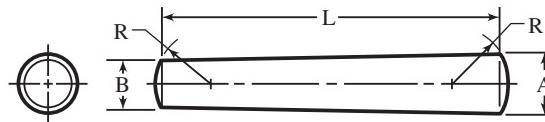
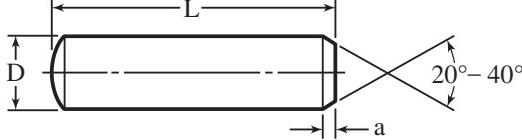


Table 13. Standard Parallel Steel Dowel Pins — Metric Series
B.S. 1804: Part 2: 1968



| Nom. Length <i>L</i> , mm | Nominal Diameter <i>D</i> , mm | | | | | | | | | | | | | | | |
|---------------------------------|--------------------------------|-----|----|-----|------------------|----|------|---|---|-----|----|----|----|----|---|--|
| | 1 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | | |
| | Chamfer <i>a</i> max, mm | | | | | | | | | | | | | | | |
| Standard Sizes | | | | | | | | | | | | | | | | |
| 4 | 0 | 0 | | | | | | | | | | | | | | |
| 6 | 0 | 0 | 0 | 0 | | | | | | | | | | | | |
| 8 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| 16 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| 20 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| 25 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| 30 | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 35 | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 40 | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | |
| 45 | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 50 | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 60 | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | |
| 70 | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | |
| 80 | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | |
| 90 | | | | | | | | | | | | 0 | 0 | 0 | 0 | |
| 100 | | | | | | | | | | | | 0 | 0 | 0 | 0 | |
| 110 | | | | | | | | | | | | 0 | 0 | 0 | 0 | |
| 120 | | | | | | | | | | | | 0 | 0 | 0 | 0 | |
| Nominal Diameter, mm | Grade ^a | | | | | | | | | | | | | | | |
| | 1 | | | | 2 | | | | 3 | | | | | | | |
| | Tolerance Zone | | | | | | | | | | | | | | | |
| Over | To & Incl. | m5 | | | | h7 | | | | h11 | | | | | | |
| Limits of Tolerance, 0.001 mm | | +7 | +2 | 0 | -12 ^b | 0 | -60 | | | | | | | | | |
| 3 | 3 | +9 | +4 | 0 | -12 | 0 | -75 | | | | | | | | | |
| 3 | 6 | +12 | +6 | 0 | -15 | 0 | -90 | | | | | | | | | |
| 6 | 10 | +15 | +7 | 0 | -18 | 0 | -110 | | | | | | | | | |
| 10 | 14 | +15 | +7 | 0 | -18 | 0 | -110 | | | | | | | | | |
| 14 | 18 | +15 | +7 | 0 | -18 | 0 | -110 | | | | | | | | | |
| 18 | 24 | +17 | +8 | 0 | -21 | 0 | -130 | | | | | | | | | |
| 24 | 30 | +17 | +8 | 0 | -21 | 0 | -130 | | | | | | | | | |

^a The limits of tolerance for grades 1 and 2 dowel pins have been chosen to provide satisfactory assembly when used in standard reamed holes (H7 and H8 tolerance zones). If the assembly is not satisfactory, refer to B.S. 1916: Part 1, Limits and Fits for Engineering, and select a different class of fit.

^b This tolerance is larger than that given in BS 1916, and has been included because the use of a closer tolerance would involve precision grinding by the manufacturer, which is uneconomic for a grade 2 dowel pin.

The tolerance limits on the overall length of all grades of dowel pin up to and including 50 mm long are +0.5, -0.0 mm, and for pins over 50 mm long are +0.8, -0.0 mm. The Standard specifies that the roughness of the cylindrical surface of grades 1 and 2 dowel pins, when assessed in accordance with BS 1134, shall not be greater than 0.4 µm CLA (16 CLA).

Table 14. American National Standard Coiled Type Spring Pins ANSI B18.8.2-1995

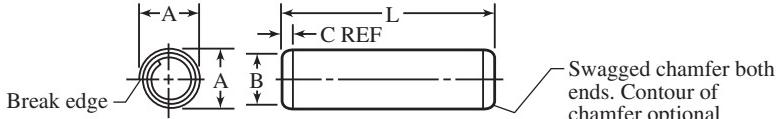
| Nominal Size ^a or Basic Pin Diameter | Pin Diameter, A | | | | | | Chamfer | | Recommended Hole Size | AISI Material Designation | | | | | | | |
|---|-----------------|-------|------------|-------|------------|-------|---------|-----------|-----------------------|---------------------------|------------------|----------------------------|--------|---------------------|--------|--------|-------|
| | Standard Duty | | Heavy Duty | | Light Duty | | Dia., B | Length, C | | 1070-1095 and 420 | 302 | 1070-1095 and 420 | 302 | 1070-1095 and 420 | | | |
| | Max | Min | Max | Min | Max | Min | Max | Ref | | Max | Min | Double Shear Load, Min, lb | | | | | |
| | Max | Min | Max | Min | Max | Min | Max | Ref | | Standard Duty | Heavy Duty | Light Duty | | | | | |
| 1/32 | 0.031 | 0.035 | 0.033 | ... | ... | ... | 0.029 | 0.024 | 0.032 | 0.031 | 75 ^b | 60 | ... | ... | ... | ... | ... |
| | 0.039 | 0.044 | 0.041 | ... | ... | ... | 0.037 | 0.024 | 0.040 | 0.039 | 120 ^b | 100 | ... | ... | ... | ... | ... |
| 3/64 | 0.047 | 0.052 | 0.049 | ... | ... | ... | 0.045 | 0.024 | 0.048 | 0.046 | 170 ^b | 140 | ... | ... | ... | ... | ... |
| | 0.052 | 0.057 | 0.054 | ... | ... | ... | 0.050 | 0.024 | 0.053 | 0.051 | 230 ^b | 190 | ... | ... | ... | ... | ... |
| 1/16 | 0.062 | 0.072 | 0.067 | 0.070 | 0.066 | 0.073 | 0.067 | 0.059 | 0.028 | 0.065 | 0.061 | 300 | 250 | 450 | 350 | ... | 135 |
| 5/64 | 0.078 | 0.088 | 0.083 | 0.086 | 0.082 | 0.089 | 0.083 | 0.075 | 0.032 | 0.081 | 0.077 | 475 | 400 | 700 | 550 | ... | 225 |
| 3/32 | 0.094 | 0.105 | 0.099 | 0.103 | 0.098 | 0.106 | 0.099 | 0.091 | 0.038 | 0.097 | 0.093 | 700 | 550 | 1,000 | 800 | 375 | 300 |
| 7/64 | 0.109 | 0.120 | 0.114 | 0.118 | 0.113 | 0.121 | 0.114 | 0.106 | 0.038 | 0.112 | 0.108 | 950 | 750 | 1,400 | 1,125 | 525 | 425 |
| 1/8 | 0.125 | 0.138 | 0.131 | 0.136 | 0.130 | 0.139 | 0.131 | 0.121 | 0.044 | 0.129 | 0.124 | 1,250 | 1,000 | 2,100 | 1,700 | 675 | 550 |
| 5/32 | 0.156 | 0.171 | 0.163 | 0.168 | 0.161 | 0.172 | 0.163 | 0.152 | 0.048 | 0.160 | 0.155 | 1,925 | 1,550 | 3,000 | 2,400 | 1,100 | 875 |
| 3/16 | 0.188 | 0.205 | 0.196 | 0.202 | 0.194 | 0.207 | 0.196 | 0.182 | 0.055 | 0.192 | 0.185 | 2,800 | 2,250 | 4,400 | 3,500 | 1,500 | 1,200 |
| 7/32 | 0.219 | 0.238 | 0.228 | 0.235 | 0.226 | 0.240 | 0.228 | 0.214 | 0.065 | 0.224 | 0.217 | 3,800 | 3,000 | 5,700 | 4,600 | 2,100 | 1,700 |
| 1/4 | 0.250 | 0.271 | 0.260 | 0.268 | 0.258 | 0.273 | 0.260 | 0.243 | 0.065 | 0.256 | 0.247 | 5,000 | 4,000 | 7,700 | 6,200 | 2,700 | 2,200 |
| 5/16 | 0.312 | 0.337 | 0.324 | 0.334 | 0.322 | 0.339 | 0.324 | 0.304 | 0.080 | 0.319 | 0.308 | 7,700 | 6,200 | 11,500 | 9,200 | 4,440 | 3,500 |
| 3/8 | 0.375 | 0.403 | 0.388 | 0.400 | 0.386 | 0.405 | 0.388 | 0.366 | 0.095 | 0.383 | 0.370 | 11,200 | 9,000 | 17,600 | 14,000 | 6,000 | 5,000 |
| 7/16 | 0.438 | 0.469 | 0.452 | 0.466 | 0.450 | 0.471 | 0.452 | 0.427 | 0.095 | 0.446 | 0.431 | 15,200 | 13,000 | 22,500 | 18,000 | 8,400 | 6,700 |
| 1/2 | 0.500 | 0.535 | 0.516 | 0.532 | 0.514 | 0.537 | 0.516 | 0.488 | 0.110 | 0.510 | 0.493 | 20,000 | 16,000 | 30,000 | 24,000 | 11,000 | 8,800 |
| 5/8 | 0.625 | 0.661 | 0.642 | 0.658 | 0.640 | ... | ... | 0.613 | 0.125 | 0.635 | 0.618 | 31,000 ^c | 25,000 | 46,000 ^c | 37,000 | ... | ... |
| 3/4 | 0.750 | 0.787 | 0.768 | 0.784 | 0.766 | ... | ... | 0.738 | 0.150 | 0.760 | 0.743 | 45,000 ^c | 36,000 | 66,000 ^c | 53,000 | ... | ... |

^aIn the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal size in decimals. Here, they are included.

^bSizes 1/32 inch through 0.052 inch are not available in AISI 1070-1095 carbon steel.

^cSizes 5/8 inch and larger are produced from AISI 6150 alloy steel, not AISI 1070-1095 carbon steel. Practical lengths, L, for sizes 1/32 through 0.052 inch are 1/8 through 5/8 inch and for the 7/16-inch size, 1/4 through 1 1/4 inches. For lengths of other sizes see Table 10.

All dimensions are in inches.



American National Standard Spring Pins.— These pins are made in two types: one type has a slot throughout its length; the other is shaped into a coil.

Preferred Lengths and Sizes: The preferred lengths and sizes in which these pins are normally available are given in Tables 14 and Table 15.

Materials: Spring pins are normally made from AISI 1070-1095 carbon steel, AISI 6150 H alloy steel, AISI Types 410 through 420 and 302 corrosion resistant steels, and beryllium copper alloy, heat treated or cold worked to attain the hardness and performance characteristics set forth in ANSI B18.8.2-1978, R1995.

Table 15. American National Standard Slotted Type Spring Pins
ANSI B18.8.2-1978, R1995

| Nominal Size ^a or Basic Pin Diameter | Average Pin Diameter, A | | Chamfer Diam., B | | Chamfer Length, C | | Stock Thickness, F | Recommended Hole Size | Material | | | Range of Practical Lengths ^b |
|---|-------------------------|-------|------------------|-------|-------------------|-------|--------------------|-----------------------|----------------------------|--------|--------|---|
| | Max | Min | Max | Min | Max | Min | | | Double Shear Load, Min, lb | | | |
| 1/16 0.062 | 0.069 | 0.066 | 0.059 | 0.028 | 0.007 | 0.012 | 0.065 | 0.062 | 425 | 350 | 270 | 3/16-1 |
| 5/64 0.078 | 0.086 | 0.083 | 0.075 | 0.032 | 0.008 | 0.018 | 0.081 | 0.078 | 650 | 550 | 400 | 3/16-1 1/2 |
| 3/32 0.094 | 0.103 | 0.099 | 0.091 | 0.038 | 0.008 | 0.022 | 0.097 | 0.094 | 1,000 | 800 | 660 | 3/16-1 1/2 |
| 1/8 0.125 | 0.135 | 0.131 | 0.122 | 0.044 | 0.008 | 0.028 | 0.129 | 0.125 | 2,100 | 1,500 | 1,200 | 5/16-2 |
| 5/64 0.141 | 0.149 | 0.145 | 0.137 | 0.044 | 0.008 | 0.028 | 0.144 | 0.140 | 2,200 | 1,600 | 1,400 | 3/8-2 |
| 3/32 0.156 | 0.167 | 0.162 | 0.151 | 0.048 | 0.010 | 0.032 | 0.160 | 0.156 | 3,000 | 2,000 | 1,800 | 7/16-2 1/2 |
| 3/16 0.188 | 0.199 | 0.194 | 0.182 | 0.055 | 0.011 | 0.040 | 0.192 | 0.187 | 4,400 | 2,800 | 2,600 | 1/2-2 1/2 |
| 7/32 0.219 | 0.232 | 0.226 | 0.214 | 0.065 | 0.011 | 0.048 | 0.224 | 0.219 | 5,700 | 3,550 | 3,700 | 1/2-3 |
| 1/4 0.250 | 0.264 | 0.258 | 0.245 | 0.065 | 0.012 | 0.048 | 0.256 | 0.250 | 7,700 | 4,600 | 4,500 | 1/2-3 1/2 |
| 5/16 0.312 | 0.328 | 0.321 | 0.306 | 0.080 | 0.014 | 0.062 | 0.318 | 0.312 | 11,500 | 7,095 | 6,800 | 3/4-4 |
| 3/8 0.375 | 0.392 | 0.385 | 0.368 | 0.095 | 0.016 | 0.077 | 0.382 | 0.375 | 17,600 | 10,000 | 10,100 | 3/4, 7/8, 1, 1 1/4, 1 1/2, 1 3/4, 2-4 |
| 7/16 0.438 | 0.456 | 0.448 | 0.430 | 0.095 | 0.017 | 0.077 | 0.445 | 0.437 | 20,000 | 12,000 | 12,200 | 1, 1 1/4, 1 1/2, 1 3/4, 2-4 |
| 1/2 0.500 | 0.521 | 0.513 | 0.485 | 0.110 | 0.025 | 0.094 | 0.510 | 0.500 | 25,800 | 15,500 | 16,800 | 1 1/4, 1 1/2, 1 3/4, 2-4 |
| 5/8 0.625 | 0.650 | 0.640 | 0.608 | 0.125 | 0.030 | 0.125 | 0.636 | 0.625 | 46,000 ^c | 18,800 | ... | 2-6 |
| 3/4 0.750 | 0.780 | 0.769 | 0.730 | 0.150 | 0.030 | 0.150 | 0.764 | 0.750 | 66,000 ^c | 23,200 | ... | ... |

^a In the Standard, zeros preceding decimal and in the fourth decimal place are omitted, when specifying nominal size in decimals. Here, they are included.

^b Length increments are $\frac{1}{16}$ inch from $\frac{1}{8}$ to 1 inch; $\frac{1}{8}$ from 1 inch to 2 inches; and $\frac{1}{4}$ inch from 2 inches to 6 inches.

^c Sizes $\frac{5}{8}$ and $\frac{3}{4}$ inch are produced from AISI 6150 H alloy steel, not AISI 1070-1095 carbon steel.

All dimensions are in inches.

Table 16. American National Standard T-Nuts ANSI/ASME B5.1M-1985, R2004

| Nominal T-Bolt Size | | T-NUTS | | | | | | | | | | | | | | Rounding of Corners | | | | | | | |
|---------------------------|----|-----------------------------|-------|-------|-------|--------------------------|------------------|--------------------------|-------|-----|-----|---------------------------|-------|------|------|---|------|--|-----|----------------|-----|----------------|-----|
| | | Width of Tongue A_3 | | | | Tap for Stud E_3 | | Width of Nut B_3 | | | | Height of Nut C_3 | | | | Total Thickness Including Tongue ^a K_3 | | Length of Nut ^a L_3 | | R ₃ | | W ₃ | |
| inch | mm | max | min | max | min | UNC-3B | ISO ^b | inch | mm | max | min | max | min | inch | mm | inch | mm | inch | mm | max | max | max | max |
| 0.250 | 4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | 5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | 6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | 8 | 0.330 | 0.320 | 8.7 | 8.5 | 0.250-20 | M6 | 0.562 | 0.531 | 15 | 14 | 0.188 | 0.172 | 6 | 5.6 | 0.281 | 9 | 0.562 | 18 | 0.02 | 0.5 | 0.03 | 0.8 |
| | 10 | 0.418 | 0.408 | 11 | 10.75 | 0.312-18 | M8 | 0.688 | 0.656 | 18 | 17 | 0.250 | 0.234 | 7 | 6.6 | 0.375 | 10.5 | 0.688 | 20 | 0.02 | 0.5 | 0.03 | 0.8 |
| | 12 | 0.543 | 0.533 | 13.5 | 13.25 | 0.375-1 | 6M10 | 0.875 | 0.844 | 22 | 21 | 0.312 | 0.297 | 8 | 7.6 | 0.531 | 12 | 0.875 | 23 | 0.02 | 0.5 | 0.06 | 1.5 |
| | 16 | 0.668 | 0.658 | 17.25 | 17 | 0.500-13 | M12 | 1.125 | 1.094 | 28 | 27 | 0.406 | 0.391 | 10 | 9.6 | 0.625 | 15 | 1.125 | 27 | 0.03 | 0.8 | 0.06 | 1.5 |
| | 20 | 0.783 | 0.773 | 20.5 | 20.25 | 0.625-11 | M16 | 1.312 | 1.281 | 34 | 33 | 0.531 | 0.500 | 14 | 13.2 | 0.781 | 21 | 1.312 | 35 | 0.03 | 0.8 | 0.06 | 1.5 |
| | 24 | 1.033 | 1.018 | 26.5 | 26 | 0.750-10 | M20 | 1.688 | 1.656 | 43 | 42 | 0.688 | 0.656 | 18 | 17.2 | 1.000 | 27 | 1.688 | 46 | 0.03 | 0.8 | 0.06 | 1.5 |
| | 30 | 1.273 | 1.258 | 33 | 32.5 | 1.000-8 | M24 | 2.062 | 2.031 | 53 | 52 | 0.938 | 0.906 | 23 | 22.2 | 1.312 | 34 | 2.062 | 53 | 0.03 | 0.8 | 0.06 | 1.5 |
| 1.500 | 36 | 1.523 | 1.508 | 39.25 | 38.75 | 1.250-7 | M30 | 2.500 | 2.469 | 64 | 63 | 1.188 | 1.156 | 28 | 27.2 | 1.625 | 42 | 2.500 | 65 | 0.03 | 0.8 | 0.06 | 1.5 |
| | 42 | | | 46.75 | 46.25 | | M36 | | | 75 | 74 | | | 32 | 30.5 | | 48 | | 75 | 1 | | 2 | |
| | 48 | | | 52.5 | 51.75 | | M42 | | | 85 | 84 | | | 36 | 34.5 | | 54 | | 85 | 1 | | 2 | |

^a No tolerances are given for "Total Thickness" or "Nut Length" as they need not be held to close limits.^b Metric tapped thread grade and tolerance position is 5H.

Table 17. Wrench Openings for Nuts ANSI/ASME B18.2.2-1987, R1999 Appendix

| Max. ^a Width Across Flats of Nut | Wrench Opening ^b | | Max. ^c Width Across Flats of Nut | Wrench Opening ^b | | Max. ^d Width Across Flats of Nut | Wrench Opening ^b | |
|---|-----------------------------|-------|---|-----------------------------|--------------|---|-----------------------------|--------------|
| | Min. | Max. | | Min. | Max. | | Min. | Max. |
| $\frac{5}{32}$ | 0.158 | 0.163 | $1\frac{1}{4}$ | 1.257 | 1.267 | $2\frac{15}{16}$ | 2.954 | 2.973 |
| $\frac{3}{16}$ | 0.190 | 0.195 | $1\frac{5}{16}$ | 1.320 | 1.331 | 3 | 3.016 | 3.035 |
| $\frac{7}{32}$ | 0.220 | 0.225 | $1\frac{3}{8}$ | <i>1.383</i> | <i>1.394</i> | $3\frac{1}{8}$ | 3.142 | 3.162 |
| $\frac{1}{4}$ | 0.252 | 0.257 | $1\frac{7}{16}$ | 1.446 | 1.457 | $3\frac{3}{8}$ | <i>3.393</i> | <i>3.414</i> |
| $\frac{9}{32}$ | 0.283 | 0.288 | $1\frac{1}{2}$ | 1.508 | 1.520 | $3\frac{1}{2}$ | 3.518 | 3.540 |
| $\frac{5}{16}$ | 0.316 | 0.322 | $1\frac{5}{8}$ | 1.634 | 1.646 | $3\frac{3}{4}$ | 3.770 | 3.793 |
| $1\frac{1}{32}$ | 0.347 | 0.353 | $1\frac{11}{16}$ | 1.696 | 1.708 | $3\frac{7}{8}$ | 3.895 | 3.918 |
| $\frac{3}{8}$ | 0.378 | 0.384 | $1\frac{13}{16}$ | 1.822 | 1.835 | $4\frac{1}{8}$ | 4.147 | 4.172 |
| $\frac{7}{16}$ | 0.440 | 0.446 | $1\frac{7}{8}$ | 1.885 | 1.898 | $4\frac{1}{4}$ | 4.272 | 4.297 |
| $\frac{1}{2}$ | 0.504 | 0.510 | 2 | 2.011 | 2.025 | $4\frac{1}{2}$ | 4.524 | 4.550 |
| $\frac{9}{16}$ | 0.566 | 0.573 | $2\frac{1}{16}$ | 2.074 | 2.088 | $4\frac{5}{8}$ | 4.649 | 4.676 |
| $\frac{5}{8}$ | 0.629 | 0.636 | $2\frac{3}{16}$ | 2.200 | 2.215 | $4\frac{7}{8}$ | 4.900 | 4.928 |
| $1\frac{1}{16}$ | 0.692 | 0.699 | $2\frac{1}{4}$ | 2.262 | 2.277 | 5 | 5.026 | 5.055 |
| $\frac{3}{4}$ | 0.755 | 0.763 | $2\frac{3}{8}$ | 2.388 | 2.404 | $5\frac{1}{4}$ | 5.277 | 5.307 |
| $1\frac{3}{16}$ | 0.818 | 0.826 | $2\frac{7}{16}$ | <i>2.450</i> | <i>2.466</i> | $5\frac{3}{8}$ | 5.403 | 5.434 |
| $\frac{7}{8}$ | 0.880 | 0.888 | $2\frac{9}{16}$ | 2.576 | 2.593 | $5\frac{5}{8}$ | 5.654 | 5.686 |
| $1\frac{5}{16}$ | 0.944 | 0.953 | $2\frac{5}{8}$ | 2.639 | 2.656 | $5\frac{3}{4}$ | 5.780 | 5.813 |
| 1 | 1.006 | 1.015 | $2\frac{3}{4}$ | 2.766 | 2.783 | 6 | 6.031 | 6.157 |
| $\frac{1}{16}$ | 1.068 | 1.077 | $2\frac{13}{16}$ | 2.827 | 2.845 | $6\frac{1}{8}$ | 6.065 | 6.192 |
| $1\frac{1}{8}$ | 1.132 | 1.142 | | | | | | |

^a Wrenches are marked with the "Nominal Size of Wrench," which is equal to the basic or maximum width across flats of the corresponding nut. Minimum wrench opening is $(1.005W + 0.001)$. Tolerance on wrench opening is $(0.005W + 0.004)$ from minimum, where W equals nominal size of wrench.

^b Openings for $\frac{5}{32}$ to $\frac{3}{8}$ widths from old ASA B18.2-1960 and italic values are from former ANSI B18.2.2-1972.

^c Wrenches are marked with the "Nominal Size of Wrench," which is equal to the basic or maximum width across flats of the corresponding nut. Minimum wrench opening is $(1.005W + 0.001)$. Tolerance on wrench opening is $(0.005W + 0.004)$ from minimum, where W equals nominal size of wrench.

^d Wrenches are marked with the "Nominal Size of Wrench," which is equal to the basic or maximum width across flats of the corresponding nut. Minimum wrench opening is $(1.005W + 0.001)$. Tolerance on wrench opening is $(0.005W + 0.004)$ from minimum, where W equals nominal size of wrench.

All dimensions given in inches.

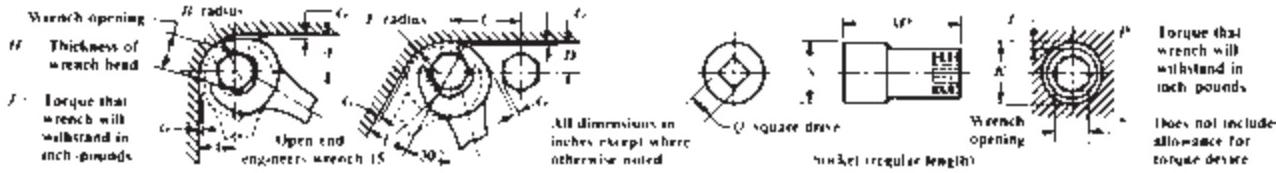
Table 18. Wrench Clearances for Box Wrench—12 Point
From SAE Aeronautical Drafting Manual

| Wrench Opening | A Min. | B Min. | C Ref. | D Max. | E Min. | Wrench Opening | A Min. | B Min. | C Ref. | D Max. | E Min. |
|----------------|--------|--------|--------|--------|--------|----------------|--------|--------|--------|--------|--------|
| 0.156 | 0.190 | 0.280 | 0.030 | 0.156 | 100 | 0.781 | 0.690 | 1.140 | 0.030 | 0.594 | 2600 |
| 0.188 | 0.200 | 0.309 | 0.030 | 0.172 | 150 | 0.812 | 0.720 | 1.190 | 0.030 | 0.594 | 3000 |
| 0.250 | 0.270 | 0.410 | 0.030 | 0.250 | 150 | 0.875 | 0.750 | 1.260 | 0.030 | 0.594 | 3300 |
| 0.312 | 0.300 | 0.480 | 0.030 | 0.281 | 210 | 0.938 | 0.780 | 1.320 | 0.030 | 0.656 | 4100 |
| 0.344 | 0.300 | 0.500 | 0.030 | 0.281 | 250 | 1.000 | 0.810 | 1.390 | 0.030 | 0.718 | 4900 |
| 0.375 | 0.340 | 0.560 | 0.030 | 0.344 | 370 | 1.062 | 0.840 | 1.450 | 0.030 | 0.781 | 5400 |
| 0.438 | 0.400 | 0.650 | 0.030 | 0.359 | 650 | 1.125 | 0.950 | 1.600 | 0.030 | 0.844 | 5900 |
| 0.500 | 0.450 | 0.740 | 0.030 | 0.375 | 1020 | 1.250 | 0.980 | 1.700 | 0.030 | 0.875 | 7200 |
| 0.562 | 0.500 | 0.830 | 0.030 | 0.406 | 1200 | 1.312 | 1.090 | 1.850 | 0.030 | 0.906 | 8000 |
| 0.594 | 0.530 | 0.870 | 0.030 | 0.469 | 1200 | 1.438 | 1.220 | 2.050 | 0.030 | 1.000 | 8400 |
| 0.625 | 0.560 | 0.920 | 0.030 | 0.469 | 2000 | 1.500 | 1.270 | 2.140 | 0.030 | 1.062 | 10450 |
| 0.688 | 0.590 | 0.990 | 0.030 | 0.531 | 2300 | 1.625 | 1.340 | 2.280 | 0.030 | 1.156 | 11750 |
| 0.750 | 0.660 | 1.090 | 0.030 | 0.594 | 2600 | ... | ... | ... | ... | ... | ... |



Table 19. Wrench Clearances for Open End Engineers Wrench 15° and Socket Wrench (Regular Length)
From SAE Aeronautical Drafting Manual

| Wrench Opening | Open End Engineers Wrench 15° | | | | | | | Socket (Regular Length) | | | | | | | | | | | | Wren ch Open- ing |
|-------------------|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------|----------------------------|
| | A Min. | B Max. | C Min. | D Min. | E Min. | F Max. | G Ref. | H Max. | J Min. | K Min. | L Ref. | Q = .250 | | | Q = .375 | | | Q = .500 | | |
| | M Max. | N Max. | P Min. | M Max. | N Max. | P Min. | M Max. | N Max. | P Min. | M Max. | N Max. | P Min. | M Max. | N Max. | P Min. | M Max. | N Max. | P Min. | | |
| 0.156 | 0.220 | 0.250 | 0.390 | 0.160 | 0.250 | 0.200 | 0.030 | 0.094 | 25 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.188 | 0.250 | 0.280 | 0.430 | 0.190 | 0.270 | 0.230 | 0.030 | 0.172 | 40 | 0.370 | 0.030 | 1.000 | 0.510 | 125 | ... | ... | ... | ... | ... | 0.188 |
| 0.250 | 0.280 | 0.340 | 0.530 | 0.270 | 0.310 | 0.310 | 0.030 | 0.172 | 60 | 0.470 | 0.030 | 1.000 | 0.510 | 200 | 1.250 | 0.690 | 250 | ... | ... | 0.250 |
| 0.312 | 0.380 | 0.470 | 0.660 | 0.280 | 0.390 | 0.390 | 0.050 | 0.203 | 125 | 0.550 | 0.030 | 1.000 | 0.510 | 300 | 1.250 | 0.690 | 400 | ... | ... | 0.312 |
| 0.344 | 0.420 | 0.500 | 0.750 | 0.340 | 0.450 | 0.450 | 0.050 | 0.203 | 175 | 0.580 | 0.030 | 1.000 | 0.519 | 450 | 1.250 | 0.690 | 675 | ... | ... | 0.344 |
| 0.375 | 0.420 | 0.500 | 0.780 | 0.360 | 0.450 | 0.520 | 0.050 | 0.219 | 250 | 0.620 | 0.030 | 1.000 | 0.580 | 550 | 1.250 | 0.690 | 900 | 1.500 | 0.880 | 1600 |
| 0.438 | 0.470 | 0.590 | 0.890 | 0.420 | 0.520 | 0.640 | 0.050 | 0.250 | 375 | 0.750 | 0.030 | 1.000 | 0.683 | 550 | 1.250 | 0.880 | 1250 | 1.500 | 0.940 | 1700 |
| 0.500 | 0.520 | 0.640 | 1.000 | 0.470 | 0.580 | 0.660 | 0.050 | 0.266 | 490 | 0.810 | 0.030 | 1.000 | 0.692 | 600 | 1.250 | 0.880 | 1450 | 1.500 | 0.940 | 2000 |
| 0.562 | 0.590 | 0.770 | 1.130 | 0.520 | 0.660 | 0.700 | 0.050 | 0.297 | 700 | 0.870 | 0.030 | ... | ... | ... | 1.250 | 0.932 | 1600 | 1.500 | 0.940 | 2700 |
| 0.594 | 0.640 | 0.830 | 1.210 | 0.530 | 0.700 | 0.700 | 0.050 | 0.344 | 800 | 0.920 | 0.030 | ... | ... | ... | 1.250 | 0.963 | 1750 | 1.562 | 0.970 | 3000 |
| 0.625 | 0.640 | 0.830 | 1.230 | 0.550 | 0.700 | 0.700 | 0.050 | 0.344 | 935 | 0.950 | 0.030 | ... | ... | ... | 1.250 | 0.995 | 2000 | 1.562 | 1.000 | 3600 |
| 0.688 | 0.770 | 0.920 | 1.470 | 0.660 | 0.880 | 0.800 | 0.060 | 0.375 | 1250 | 1.030 | 0.030 | ... | ... | ... | 1.250 | 1.058 | 2000 | 1.562 | 1.065 | 4300 |
| 0.750 | 0.770 | 0.920 | 1.510 | 0.670 | 0.880 | 0.800 | 0.060 | 0.375 | 1500 | 1.120 | 0.030 | ... | ... | ... | 1.250 | 1.120 | 2000 | 1.562 | 1.130 | 5000 |
| 0.781 | 0.830 | 0.950 | 1.550 | 0.690 | 0.890 | 0.840 | 0.060 | 0.375 | 1615 | 1.150 | 0.030 | ... | ... | ... | 1.250 | 1.126 | 2000 | 1.625 | 1.130 | 5000 |
| 0.812 | 0.910 | 1.120 | 1.660 | 0.720 | 0.970 | 0.860 | 0.060 | 0.406 | 1710 | 1.200 | 0.030 | ... | ... | ... | 1.250 | 1.213 | 2000 | 1.625 | 1.222 | 5000 |
| 0.875 | 0.970 | 1.150 | 1.810 | 0.800 | 1.060 | 0.910 | 0.060 | 0.438 | 2250 | 1.280 | 0.030 | ... | ... | ... | ... | ... | 1.750 | 1.285 | 5000 | ... |
| 0.938 | 0.970 | 1.150 | 1.850 | 0.810 | 1.060 | 0.950 | 0.060 | 0.438 | 2750 | 1.370 | 0.030 | ... | ... | ... | ... | ... | 1.750 | 1.410 | 5000 | ... |
| 1.000 | 1.050 | 1.230 | 2.000 | 0.880 | 1.160 | 1.060 | 0.060 | 0.500 | 3250 | 1.470 | 0.030 | ... | ... | ... | ... | ... | 1.750 | 1.410 | 5000 | ... |
| 1.062 | 1.090 | 1.250 | 2.100 | 0.970 | 1.200 | 1.200 | 0.080 | 0.500 | 3500 | 1.550 | 0.030 | ... | ... | ... | ... | ... | 1.844 | 1.505 | 5000 | ... |
| 1.125 | 1.140 | 1.370 | 2.210 | 1.000 | 1.270 | 1.230 | 0.080 | 0.500 | 4000 | 1.610 | 0.030 | ... | ... | ... | ... | ... | 1.938 | 1.567 | 5000 | ... |
| 1.250 | 1.270 | 1.420 | 2.440 | 1.080 | 1.390 | 1.310 | 0.080 | 0.562 | 5250 | 1.890 | 0.030 | ... | ... | ... | ... | ... | 2.000 | 1.723 | 5000 | 2.375 |
| 1.312 | 1.390 | 1.690 | 2.630 | 1.170 | 1.520 | 1.340 | 0.080 | 0.562 | 6000 | 1.980 | 0.030 | ... | ... | ... | ... | ... | ... | ... | 2.500 | 1.920 |
| 1.438 | 1.470 | 1.720 | 2.800 | 1.250 | 1.590 | 1.340 | 0.090 | 0.641 | 7500 | 2.140 | 0.030 | ... | ... | ... | ... | ... | ... | ... | 2.625 | 2.075 |
| 1.500 | 1.470 | 1.720 | 2.840 | 1.270 | 1.590 | 1.450 | 0.090 | 0.641 | 8250 | 2.200 | 0.030 | ... | ... | ... | ... | ... | ... | ... | 2.625 | 2.170 |
| 1.625 | 1.560 | 1.880 | 3.100 | 1.380 | 1.750 | 1.560 | 0.090 | 0.641 | 9000 | 2.390 | 0.030 | ... | ... | ... | ... | ... | ... | ... | 2.750 | 2.325 |



Bolts and Screws Specification

The following definitions are based on *Specification for Identification of Bolts and Screws*, ANSI/ASME B18.2.1 1981. This specification establishes a recommended procedure for determining the identity of an externally threaded fastener as a bolt or as a screw.

Bolt: A bolt is an externally threaded fastener designed for insertion through the holes in assembled parts, and is normally intended to be tightened or released by torquing a nut.

Screw: A screw is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by torquing the head.

Primary Criteria.— 1) An externally threaded fastener, which because of head design or other feature, is prevented from being turned during assembly, and which can be tightened or released only by torquing a nut, is a bolt. *Example:* Round head bolts, track bolts, plow bolts.

2) An externally threaded fastener, which has a thread form which prohibits assembly with a nut having a straight thread of multiple pitch length, is a screw. *Example:* Wood screws, tapping screws.

3) An externally threaded fastener, which must be assembled with a nut to perform its intended service, is a bolt. *Example:* Heavy hex structural bolt.

4) An externally threaded fastener, that must be torqued by its head into a tapped or pre-formed hole to perform its intended service is a screw. *Example:* Square head set screw.

British Unified Machine Screws and Nuts.—Identification: As revised by Amendment No. 1 in February 1955, this standard now requires that the above-mentioned screws and nuts that conform to this standard should have a distinguishing feature applied to identify them as Unified. All *recessed head screws* are to be identified as Unified by a groove in the form of four arcs of a circle in the upper surface of the head. All *hexagon head screws* are to be identified as Unified by: 1) a circular recess in the upper surface of the head; 2) a continuous line of circles indented on one or more of the flats of the hexagon and parallel to the screw axis; and 3) at least two contiguous circles indented on the upper surface of the head. All *machine screw nuts* of the pressed type shall be identified as Unified by means of the application of a groove indented in one face of the nut approximately midway between the major diameter of the thread and flats of the square or hexagon. *Slotted head screws* shall be identified as Unified either by a circular recess or by a circular platform or raised portion on the upper surface of the head. *Machine screw nuts* of the *precision type* shall be identified as Unified by either a groove indented on one face of the front approximately midway between the major diameter of the thread and the flats of the hexagon or a continuous line of circles indented on one or more of the flats of the hexagon and parallel to the nut axis.

Identification Markings for British Standard Unified Machine Screws



Recessed and Hexagon Head Screws



Precision Type



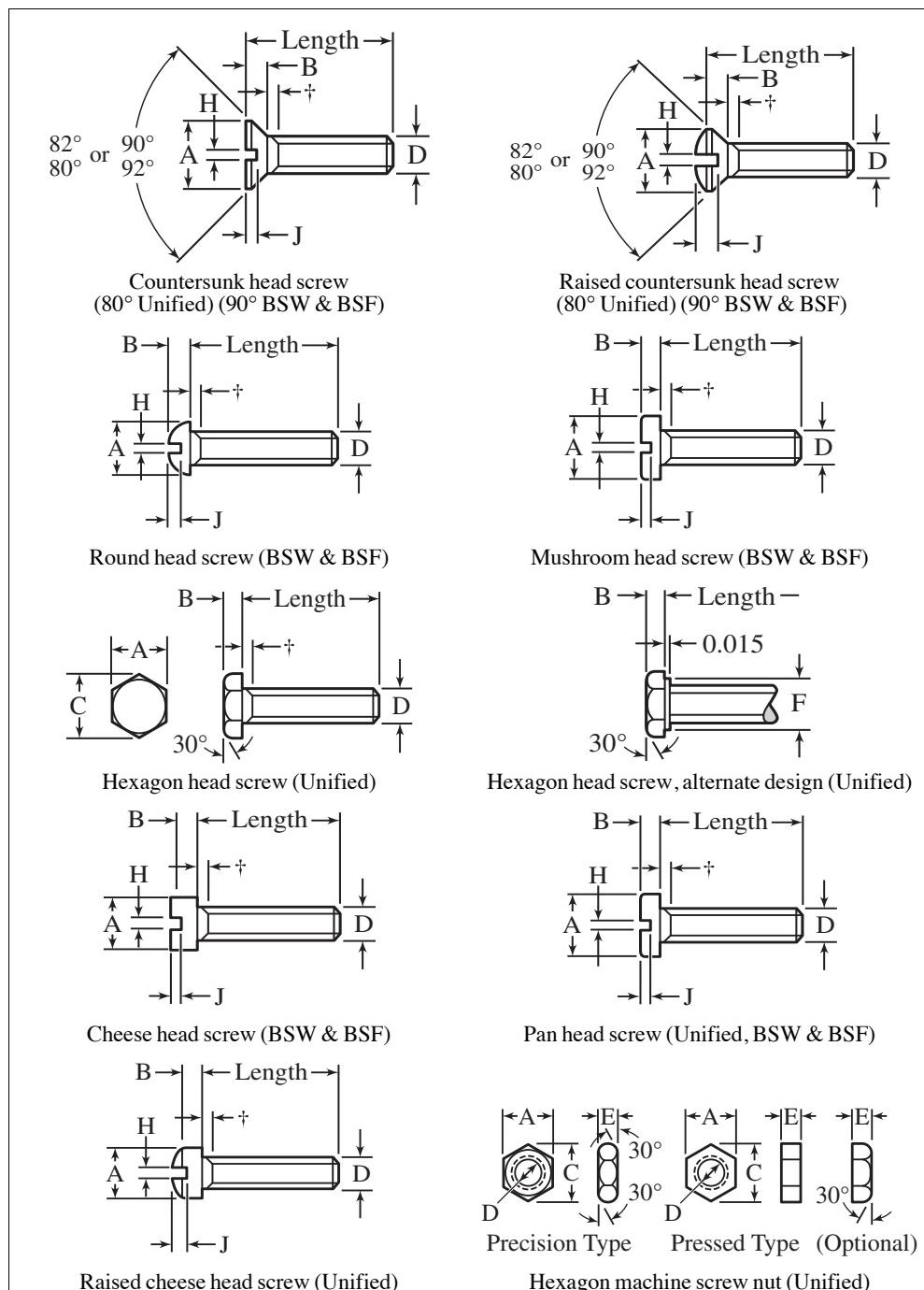
Pressed Type

Hexagon Machine Screw Nuts



Slotted Head Screws

Table 20. British Standard Machine Screws and Nuts
BS 450:1958 and BS 1981:1953



*Countersinks to suit the screws should have a maximum angle of 80° (Unified) or 90° (B.S.F. and B.S.W.) with a negative tolerance.

†Unified countersunk and raised countersunk head screws 2 inches long and under are threaded right up to the head. Other Unified, B.S.W. and B.S.F. machine screws 2 inches long and under have an unthreaded shank equal to twice the pitch. All Unified, B.S.W. and B.S.F. machine screws longer than 2 inches have a minimum thread length of $1\frac{3}{4}$ inches.

Table 21a. British Standard Unified Machine Screws and Nuts BS 1981:1953

| Nom. Size | Basic Dia. <i>D</i> | Threads per Inch | Width Across | | | H'd Depth <i>B</i> Nut Thick. <i>E</i> | | Wash. Face Dia. <i>F</i> | | |
|---|---------------------------|---------------------|--------------|--------|-----------|---|-------|-----------------------------|-------|-------|
| | | | Flats A | | Corners C | Max. | Min. | Max. | Min. | |
| | | UNC | UNF | Max. | Min. | Max. | Max. | Min. | Max. | |
| Hexagon Head Screws | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.1875 | 0.1835 | 0.216 | 0.060 | 0.055 | 0.183 | 0.173 |
| 6 | 0.138 | 32 | ... | 0.2500 | 0.2450 | 0.289 | 0.080 | 0.074 | 0.245 | 0.235 |
| 8 | 0.164 | 32 | ... | 0.2500 | 0.2450 | 0.289 | 0.110 | 0.104 | 0.245 | 0.235 |
| 10 | 0.190 | 24 ^c | 32 | 0.3125 | 0.3075 | 0.361 | 0.120 | 0.113 | 0.307 | 0.297 |
| Hexagon Machine Screw Nuts—Precision Type | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.1875 | 0.1835 | 0.216 | 0.098 | 0.087 | ... | ... |
| 6 | 0.138 | 32 | ... | 0.2500 | 0.2450 | 0.269 | 0.114 | 0.102 | ... | ... |
| 8 | 0.164 | 32 | ... | 0.3125 | 0.3075 | 0.361 | 0.130 | 0.117 | ... | ... |
| 10 | 0.190 | 24 ^c | ... | 0.3125 | 0.3075 | 0.361 | 0.130 | 0.117 | ... | ... |
| Hexagon Machine Screw Nuts—Pressed Type | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.2500 | 0.2410 | 0.289 | 0.087 | 0.077 | ... | ... |
| 6 | 0.138 | 32 | ... | 0.3125 | 0.3020 | 0.361 | 0.114 | 0.102 | ... | ... |
| 8 | 0.164 | 32 | ... | 0.3438 | 0.3320 | 0.397 | 0.130 | 0.117 | ... | ... |
| 10 | 0.190 | 24 ^c | 32 | 0.3750 | 0.3620 | 0.433 | 0.130 | 0.117 | ... | ... |
| 1/4 | 0.250 | 20 | 28 | 0.4375 | 0.4230 | 0.505 | 0.193 | 0.178 | ... | ... |
| 5/16 | 0.3125 | 18 | 24 | 0.5625 | 0.5450 | 0.649 | 0.225 | 0.208 | ... | ... |
| 3/8 | 0.375 | 16 | 24 | 0.6250 | 0.6070 | 0.722 | 0.257 | 0.239 | ... | ... |

**Table 21b. British Standard Unified Machine Screws and Nuts
BS 1981:1953**

| Nom. Size of Screw | Basic Dia. <i>D</i> | Threads per Inch | | Dia. of Head A | | Depth of Head <i>B</i> | | Width of Slot <i>H</i> | | Depth of Slot <i>J</i> |
|--|------------------------|------------------|-----|----------------|--------------------|------------------------|-------|------------------------|-------|---------------------------|
| | | UNC | UNF | Max. | Min. | Max. | Min. | Max. | Min. | |
| 80° Countersunk Head Screws ^{a,b} | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.211 | 0.194 | 0.067 | ... | 0.039 | 0.031 | 0.025 |
| 6 | 0.138 | 32 | ... | 0.260 | 0.242 | 0.083 | ... | 0.048 | 0.039 | 0.031 |
| 8 | 0.164 | 32 | ... | 0.310 | 0.291 | 0.100 | ... | 0.054 | 0.045 | 0.037 |
| 10 | 0.190 | 24 ^c | 32 | 0.359 | 0.339 | 0.116 | ... | 0.060 | 0.050 | 0.044 |
| 1/4 | 0.250 | 20 | 28 | 0.473 | 0.450 | 0.153 | ... | 0.075 | 0.064 | 0.058 |
| 5/16 | 0.3125 | 18 | 24 | 0.593 | 0.565 | 0.191 | ... | 0.084 | 0.072 | 0.073 |
| 3/8 | 0.375 | 16 | 24 | 0.712 | 0.681 | 0.230 | ... | 0.094 | 0.081 | 0.086 |
| 7/16 | 0.4375 | 14 | 20 | 0.753 | 0.719 | 0.223 | ... | 0.094 | 0.081 | 0.086 |
| 1/2 | 0.500 | 13 | 20 | 0.808 | 0.770 | 0.223 | ... | 0.106 | 0.091 | 0.086 |
| 5/8 | 0.625 | 11 | 18 | 1.041 | 0.996 | 0.298 | ... | 0.133 | 0.116 | 0.113 |
| 3/4 | 0.750 | 10 | 16 | 1.275 | 1.223 | 0.372 | ... | 0.149 | 0.131 | 0.141 |
| Pan Head Screws ^b | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.219 | 0.205 | 0.068 | 0.058 | 0.039 | 0.031 | 0.036 |
| 6 | 0.138 | 32 | ... | 0.270 | 0.256 | 0.082 | 0.072 | 0.048 | 0.039 | 0.044 |
| 8 | 0.164 | 32 | ... | 0.322 | 0.306 | 0.096 | 0.085 | 0.054 | 0.045 | 0.051 |
| 10 | 0.190 | 24 ^c | 32 | 0.373 | 0.357 | 0.110 | 0.099 | 0.060 | 0.050 | 0.059 |
| 1/4 | 0.250 | 20 | 28 | 0.492 | 0.473 ^d | 0.144 | 0.130 | 0.075 | 0.064 | 0.079 |
| 5/16 | 0.3125 | 18 | 24 | 0.615 | 0.594 | 0.178 | 0.162 | 0.084 | 0.072 | 0.101 |
| 3/8 | 0.375 | 16 | 24 | 0.740 | 0.716 | 0.212 | 0.195 | 0.094 | 0.081 | 0.122 |

**Table 21b. (Continued) British Standard Unified Machine Screws and Nuts
BS 1981:1953**

| Nom. Size of Screw | Basic Dia. <i>D</i> | Threads per Inch | | Dia. of Head A | | Depth of Head B | | Width of Slot H | | Depth of Slot J |
|--|------------------------|------------------|-----|----------------|-------|-----------------|-------|-----------------|-------|--------------------|
| | | UNC | UNF | Max. | Min. | Max. | Min. | Max. | Min. | |
| 7/16 | 0.4375 | 14 | 20 | 0.863 | 0.838 | 0.247 | 0.227 | 0.094 | 0.081 | 0.133 |
| 1/2 | 0.500 | 13 | 20 | 0.987 | 0.958 | 0.281 | 0.260 | 0.106 | 0.091 | 0.152 |
| 5/8 | 0.625 | 11 | 18 | 1.125 | 1.090 | 0.350 | 0.325 | 0.133 | 0.116 | 0.189 |
| 3/4 | 0.750 | 10 | 16 | 1.250 | 1.209 | 0.419 | 0.390 | 0.149 | 0.131 | 0.226 |
| Raised Cheese-Head Screws ^b | | | | | | | | | | |
| 4 | 0.112 | 40 | ... | 0.183 | 0.166 | 0.107 | 0.088 | 0.039 | 0.031 | 0.042 |
| 6 | 0.138 | 32 | ... | 0.226 | 0.208 | 0.132 | 0.111 | 0.048 | 0.039 | 0.053 |
| 8 | 0.164 | 32 | ... | 0.270 | 0.250 | 0.156 | 0.133 | 0.054 | 0.045 | 0.063 |
| 10 | 0.190 | 24 ^c | 32 | 0.313 | 0.292 | 0.180 | 0.156 | 0.060 | 0.050 | 0.074 |
| 1/4 | 0.250 | 20 | 28 | 0.414 | 0.389 | 0.237 | 0.207 | 0.075 | 0.064 | 0.098 |
| 5/16 | 0.3125 | 18 | 24 | 0.518 | 0.490 | 0.295 | 0.262 | 0.084 | 0.072 | 0.124 |
| 3/8 | 0.375 | 16 | 24 | 0.622 | 0.590 | 0.355 | 0.315 | 0.094 | 0.081 | 0.149 |
| 7/16 | 0.4375 | 14 | 20 | 0.625 | 0.589 | 0.368 | 0.321 | 0.094 | 0.081 | 0.153 |
| 1/2 | 0.500 | 13 | 20 | 0.750 | 0.710 | 0.412 | 0.362 | 0.106 | 0.091 | 0.171 |
| 5/8 | 0.625 | 11 | 18 | 0.875 | 0.827 | 0.521 | 0.461 | 0.133 | 0.116 | 0.217 |
| 3/4 | 0.750 | 10 | 16 | 1.000 | 0.945 | 0.612 | 0.542 | 0.149 | 0.131 | 0.254 |

^a All dimensions, except *J*, given for the No. 4 to 3/8-inch sizes, incl., also apply to all the 80° Raised Countersunk Head Screws given in the Standard.

^b Also available with recessed heads.

^c Non-preferred.

^d By arrangement may also be 0.468.

All dimensions in inches.

Table 22. British Standard Whitworth (B.S.W.) and Fine (B.S.F.) Machine Screw BS 450:1958

| Nom. Size of Screw | Basic Dia. <i>D</i> | Threads per Inch | | Dia. of Head A | | Depth of Head B | | Width of Slot H | | Depth of Slot J |
|---|---------------------------|---------------------|-----------------|-------------------|--------------------|--------------------|-------|--------------------|-------|--------------------|
| | | B.S.W. | B.S.F. | Max. | Min. | Max. | Min. | Max. | Min. | |
| 90° Countersunk Head Screws ^{ab} | | | | | | | | | | |
| 1/8 | 0.1250 | 40 | ... | 0.219 | 0.201 | 0.056 | ... | 0.039 | 0.032 | 0.027 |
| 5/16 | 0.1875 | 24 | 32 ^c | 0.328 | 0.307 | 0.084 | ... | 0.050 | 0.042 | 0.041 |
| 3/32 | 0.2188 | ... | 28 ^c | 0.383 | 0.360 | 0.098 | ... | 0.055 | 0.046 | 0.048 |
| 1/4 | 0.2500 | 20 | 26 | 0.438 | 0.412 | 0.113 | ... | 0.061 | 0.051 | 0.055 |
| 5/16 | 0.3125 | 18 | 22 | 0.547 | 0.518 | 0.141 | ... | 0.071 | 0.061 | 0.069 |
| 3/8 | 0.3750 | 16 | 20 | 0.656 | 0.624 | 0.169 | ... | 0.082 | 0.072 | 0.083 |
| 7/16 | 0.4375 | 14 | 18 | 0.766 | 0.729 | 0.197 | ... | 0.093 | 0.082 | 0.097 |
| 1/2 | 0.5000 | 12 | 16 | 0.875 | 0.835 | 0.225 | ... | 0.104 | 0.092 | 0.111 |
| 5/16 | 0.5625 | 12 ^c | 16 ^c | 0.984 | 0.941 | 0.253 | ... | 0.115 | 0.103 | 0.125 |
| 3/8 | 0.6250 | 11 | 14 | 1.094 | 1.046 | 0.281 | ... | 0.126 | 0.113 | 0.138 |
| 3/4 | 0.7500 | 10 | 12 | 1.312 | 1.257 | 0.338 | ... | 0.148 | 0.134 | 0.166 |
| Round Head Screws ^b | | | | | | | | | | |
| 1/8 | 0.1250 | 40 | ... | 0.219 | 0.206 | 0.087 | 0.082 | 0.039 | 0.032 | 0.048 |
| 5/16 | 0.1875 | 24 | 32 ^c | 0.328 | 0.312 ^d | 0.131 | 0.124 | 0.050 | 0.042 | 0.072 |
| 3/32 | 0.2188 | ... | 28 ^c | 0.383 | 0.365 | 0.153 | 0.145 | 0.055 | 0.046 | 0.084 |
| 1/4 | 0.2500 | 20 | 26 | 0.438 | 0.417 | 0.175 | 0.165 | 0.061 | 0.051 | 0.096 |
| 5/16 | 0.3125 | 18 | 22 | 0.547 | 0.524 | 0.219 | 0.207 | 0.071 | 0.061 | 0.120 |

Table 22. (Continued) British Standard Whitworth (B.S.W.) and Fine (B.S.F.) Machine Screw BS 450:1958

| Nom. Size of Screw | Basic Dia. <i>D</i> | Threads per Inch | | Dia. of Head A | | Depth of Head B | | Width of Slot H | | Depth of Slot J |
|-----------------------------------|---------------------------|---------------------|-----------------|-------------------|--------------------|--------------------|-------|--------------------|-------|--------------------|
| | | B.S.W. | B.S.F. | Max. | Min. | Max. | Min. | Max. | Min. | |
| $\frac{3}{8}$ | 0.3750 | 16 | 20 | 0.656 | 0.629 | 0.262 | 0.249 | 0.082 | 0.072 | 0.144 |
| $\frac{7}{16}$ | 0.4375 | 14 | 18 | 0.766 | 0.735 | 0.306 | 0.291 | 0.093 | 0.082 | 0.168 |
| $\frac{1}{2}$ | 0.5000 | 12 | 16 | 0.875 | 0.840 | 0.350 | 0.333 | 0.104 | 0.092 | 0.192 |
| $\frac{9}{16}$ | 0.5625 | 12 ^c | 16 ^c | 0.984 | 0.946 | 0.394 | 0.375 | 0.115 | 0.103 | 0.217 |
| $\frac{5}{8}$ | 0.6250 | 11 | 14 | 1.094 | 1.051 | 0.437 | 0.417 | 0.126 | 0.113 | 0.240 |
| $\frac{3}{4}$ | 0.7500 | 10 | 12 | 1.312 | 1.262 | 0.525 | 0.500 | 0.148 | 0.134 | 0.288 |
| Pan Head Screws ^b | | | | | | | | | | |
| $\frac{1}{8}$ | 0.1250 | 40 | ... | 0.245 | 0.231 | 0.075 | 0.065 | 0.039 | 0.032 | 0.040 |
| $\frac{3}{16}$ | 0.1875 | 24 | 32 ^c | 0.373 | 0.375 | 0.110 | 0.099 | 0.050 | 0.042 | 0.061 |
| $\frac{7}{32}$ | 0.2188 | ... | 28 ^c | 0.425 | 0.407 | 0.125 | 0.112 | 0.055 | 0.046 | 0.069 |
| $\frac{1}{4}$ | 0.2500 | 20 | 26 | 0.492 | 0.473 ^c | 0.144 | 0.130 | 0.061 | 0.051 | 0.078 |
| $\frac{5}{16}$ | 0.3125 | 18 | 22 | 0.615 | 0.594 | 0.178 | 0.162 | 0.071 | 0.061 | 0.095 |
| $\frac{3}{8}$ | 0.3750 | 16 | 20 | 0.740 | 0.716 | 0.212 | 0.195 | 0.082 | 0.072 | 0.112 |
| $\frac{7}{16}$ | 0.4375 | 14 | 18 | 0.863 | 0.838 | 0.247 | 0.227 | 0.093 | 0.082 | 0.129 |
| $\frac{1}{2}$ | 0.5000 | 12 | 16 | 0.987 | 0.958 | 0.281 | 0.260 | 0.104 | 0.092 | 0.145 |
| $\frac{9}{16}$ | 0.5625 | 12 ^c | 16 ^c | 1.031 | 0.999 | 0.315 | 0.293 | 0.115 | 0.103 | 0.162 |
| $\frac{5}{8}$ | 0.6250 | 11 | 14 | 1.125 | 1.090 | 0.350 | 0.325 | 0.126 | 0.113 | 0.179 |
| $\frac{3}{4}$ | 0.7500 | 10 | 12 | 1.250 | 1.209 | 0.419 | 0.390 | 0.148 | 0.134 | 0.213 |
| Cheese Head Screws ^b | | | | | | | | | | |
| $\frac{1}{8}$ | 0.1250 | 40 | ... | 0.188 | 0.180 | 0.087 | 0.082 | 0.039 | 0.032 | 0.039 |
| $\frac{3}{16}$ | 0.1875 | 24 | 32 ^c | 0.281 | 0.270 | 0.131 | 0.124 | 0.050 | 0.042 | 0.059 |
| $\frac{7}{32}$ | 0.2188 | ... | 28 ^c | 0.328 | 0.315 | 0.153 | 0.145 | 0.055 | 0.046 | 0.069 |
| $\frac{1}{4}$ | 0.2500 | 20 | 26 | 0.375 | 0.360 | 0.175 | 0.165 | 0.061 | 0.051 | 0.079 |
| $\frac{5}{16}$ | 0.3125 | 18 | 22 | 0.469 | 0.450 | 0.219 | 0.207 | 0.071 | 0.061 | 0.098 |
| $\frac{3}{8}$ | 0.3750 | 16 | 20 | 0.562 | 0.540 | 0.262 | 0.249 | 0.082 | 0.072 | 0.118 |
| $\frac{7}{16}$ | 0.4375 | 14 | 18 | 0.656 | 0.630 | 0.306 | 0.291 | 0.093 | 0.082 | 0.138 |
| $\frac{1}{2}$ | 0.5000 | 12 | 16 | 0.750 | 0.720 | 0.350 | 0.333 | 0.104 | 0.092 | 0.157 |
| $\frac{9}{16}$ | 0.5625 | 12 ^c | 16 ^c | 0.844 | 0.810 | 0.394 | 0.375 | 0.115 | 0.103 | 0.177 |
| $\frac{5}{8}$ | 0.6250 | 11 | 14 | 0.938 | 0.900 | 0.437 | 0.417 | 0.126 | 0.113 | 0.197 |
| $\frac{3}{4}$ | 0.7500 | 10 | 12 | 1.125 | 1.080 | 0.525 | 0.500 | 0.148 | 0.134 | 0.236 |
| Mushroom Head Screws ^b | | | | | | | | | | |
| $\frac{1}{8}$ | 0.1250 | 40 | ... | 0.289 | 0.272 | 0.078 | 0.066 | 0.043 | 0.035 | 0.040 |
| $\frac{3}{16}$ | 0.1875 | 24 | 32 ^c | 0.448 | 0.425 | 0.118 | 0.103 | 0.060 | 0.050 | 0.061 |
| $\frac{1}{4}$ | 0.2500 | 20 | 26 | 0.573 | 0.546 | 0.150 | 0.133 | 0.075 | 0.064 | 0.079 |
| $\frac{5}{16}$ | 0.3125 | 18 | 22 | 0.698 | 0.666 | 0.183 | 0.162 | 0.084 | 0.072 | 0.096 |
| $\frac{3}{8}$ | 0.3750 | 16 | 20 | 0.823 | 0.787 | 0.215 | 0.191 | 0.094 | 0.081 | 0.112 |

^a All dimensions, except *J*, given for the $\frac{1}{8}$ through $\frac{3}{8}$ -inch sizes also apply to all the 90° Raised Countersunk Head Screw dimensions given in the Standard.

^b These screws are also available with recessed heads; dimensions of recess are not given here but may be found in the Standard.

^c Non-preferred size; avoid use whenever possible.

^d By arrangement may also be 0.309.

^e By arrangement may also be 0.468.

All dimensions in inches.

See diagram on page 102 for a pictorial representation of screws and letter dimensions.

CUTTING FLUIDS

Cutting Fluids Recommended for Machining Operations.—*Soluble Oils:* Types of oils paste compounds that form emulsions when mixed with water: Soluble oils are used extensively in machining both ferrous and non-ferrous metals when the cooling quality is paramount and the chip-bearing pressure is not excessive. Care should be taken in selecting the proper soluble oil for precision grinding operations. Grinding coolants should be free from fatty materials that tend to load the wheel, thus affecting the finish on the machined part. Soluble coolants should contain rust preventive constituents to prevent corrosion.

Mineral Oils: This group includes all types of oils extracted from petroleum such as paraffin oil, mineral seal oil, and kerosene. Mineral oils are often blended with base stocks, but they are generally used in the original form for light machining operations on both free-machining steels and non-ferrous metals. The coolants in this class should be of a type that has a relatively high flash point. Care should be taken to see that they are non-toxic, so that they will not be injurious to the operator. The heavier mineral oils (paraffin oils) usually have a viscosity of about 100 seconds at 100 degrees F. Mineral seal oil and kerosene have a viscosity of 35 to 60 seconds at 100 degrees F.

Cutting Fluids Recommended for Turning and Milling Operations

| Material to be Cut | Turning | Milling |
|-----------------------------------|--|--|
| Aluminum ^a | Mineral Oil with 10 Per cent Fat (or) Soluble Oil | Soluble Oil (96 Per Cent Water) (or) Mineral Seal Oil (or) Mineral Oil |
| Alloy Steels ^b | 25 Per Cent Sulfur base Oil ^b with 75 Per Cent Mineral Oil | 10 Per Cent Lard Oil with 90 Per Cent Mineral Oil |
| Brass | Mineral Oil with 10 Per Cent Fat | Soluble Oil (96 Per Cent Water) |
| Tool Steels and Low-carbon Steels | 25 Per Cent Lard Oil with 75 Per Cent Mineral Oil | Soluble Oil |
| Copper | Soluble Oil | Soluble Oil |
| Monel Metal | Soluble Oil | Soluble Oil |
| Cast Iron ^c | Dry | Dry |
| Malleable Iron | Soluble Oil | Soluble Oil |
| Bronze | Soluble Oil | Soluble Oil |
| Magnesium ^d | 10 Per Cent Lard Oil with 90 Per Cent Mineral Oil | Mineral Seal Oil |

^a In machining aluminum, several varieties of coolants may be used. For rough machining, where the stock removal is sufficient to produce heat, water soluble mixtures can be used with good results to dissipate the heat. Other oils that may be recommended are straight mineral seal oil; a 50-50 mixture of mineral seal oil and kerosene; a mixture of 10 per cent lard oil with 90 per cent kerosene; and a 100-second mineral oil cut back with mineral seal oil or kerosene.

^b The sulfur-base oil referred to contains 4½ per cent sulfur compound. Base oils are usually dark in color. As a rule, they contain sulfur compounds resulting from a thermal or catalytic refinery process. When so processed, they are more suitable for industrial coolants than when they have had such compounds as flowers of sulfur added by hand. The adding of sulfur compounds by hand to the coolant reservoir is of temporary value only, and the non-uniformity of the solution may affect the machining operation.

^c A soluble oil or low-viscosity mineral oil may be used in machining cast iron to prevent excessive metal dust.

^d When a cutting fluid is needed for machining magnesium, low or nonacid mineral seal or lard oils are recommended. Coolants containing water should not be used because of the fire danger when magnesium chips react with water, forming hydrogen gas.

Cutting Fluids Recommended for Drilling and Tapping Operations

| Material to be Cut | Drilling | Tapping |
|-----------------------------------|--|--|
| Aluminum ^a | Soluble Oil (75 to 90 Per Cent Water) | Lard Oil (or) Sperm Oil (or) Wool Grease |
| | (or) 10 Per Cent Lard Oil with 90 Per Cent Mineral Oil | (or) 25 Per Cent Sulfur-base Oil ^b Mixed with Mineral Oil |
| Alloy Steels ^b | Soluble Oil | 30 Per Cent Lard Oil with 70 Per Cent Mineral Oil |
| Brass | Soluble Oil (75 to 90 Per Cent Water) | 10 to 20 Per Cent Lard Oil with Mineral Oil |
| | (or) 30 Per Cent Lard Oil with 70 Per Cent Mineral Oil | |
| Tool Steels and Low-carbon Steels | Soluble Oil | 25 to 40 Per Cent Lard Oil with Mineral Oil |
| | | (or) 25 Per Cent Sulfur-base Oil ^b with 75 Per Cent Mineral Oil |
| Copper | Soluble Oil | Soluble Oil |
| Monel Metal | Soluble Oil | 25 to 40 Per Cent Lard Oil Mixed with Mineral Oil |
| | | (or) Sulfur-base Oil ^b Mixed with Mineral Oil |
| Cast Iron ^c | Dry | Dry (or) 25 Per Cent Lard Oil with 75 Per Cent Mineral Oil |
| Malleable Iron | Soluble Oil | Soluble Oil |
| Bronze | Soluble Oil | 20 Per Cent Lard Oil with 80 Per Cent Mineral Oil |
| Magnesium ^d | 60-second Mineral Oil | 20 Per Cent Lard Oil with 80 Per Cent Mineral Oil |

^aSulfurized oils ordinarily are not recommended for tapping aluminum; however, for some tapping operations they have proved very satisfactory, although the work should be rinsed in a solvent right after machining to prevent discoloration.

See additional notes following previous table.

Base Oils: Various types of highly sulfurized and chlorinated oils containing inorganic, animal, or fatty materials. This "base stock" usually is "cut back" or blended with a lighter oil, unless the chip-bearing pressures are high, as when cutting alloy steel. Base oils usually have a viscosity range of from 300 to 900 seconds at 100 degrees F.

Grinding: Soluble oil emulsions or emulsions made from paste compounds are used extensively in precision grinding operations. For cylindrical grinding, 1 part oil to 40 to 50 parts water is used. Solution type fluids and translucent grinding emulsions are particularly suited for many fine-finish grinding applications. Mineral oil-base grinding fluids are recommended for many applications where a fine surface finish is required on the ground surface. Mineral oils are used with vitrified wheels but are not recommended for wheels with rubber or shellac bonds. Under certain conditions the oil vapor mist caused by the action of the grinding wheel can be ignited by the grinding sparks and explode. To quench the grinding spark a secondary coolant line to direct a flow of grinding oil below the grinding wheel is recommended.

Broaching: For steel, a heavy mineral oil such as sulfurized oil of 300 to 500 Saybolt viscosity at 100 degrees F can be used to provide both adequate lubricating effect and a damping of the shock loads. Soluble oil emulsions may be used for the lighter broaching operations.

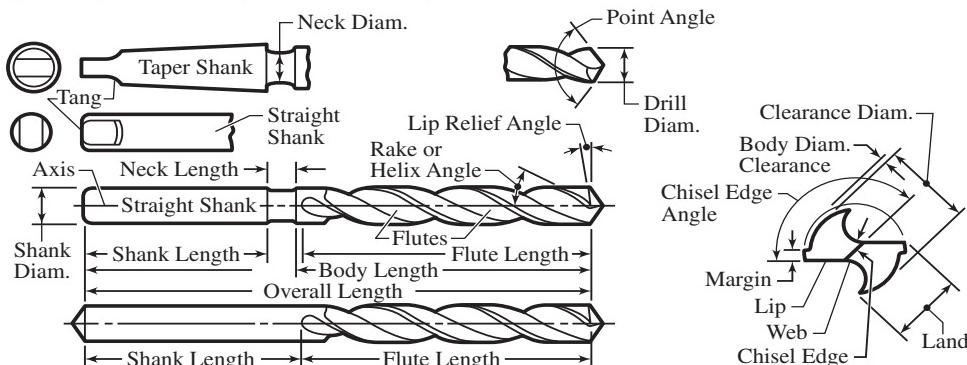
DRILLING AND REAMING

Generally Used Values for Drill Points

| Work Material | Point Angle | Comments |
|--|--|--|
| General work | 118° | Lip relief angle ^a 10°–15° Helix angle 24°–32° |
| High strength (tough) steels | 118°–135° | Lip relief angle ^a 7°–12° Helix angle 24°–32° |
| Aluminum alloys, cast iron | 90°–140° | Lip relief angle ^a 10°–15° |
| Magnesium and copper alloys | 70°–118° | Lip relief angle ^a 10°–15° Helix angle 10°–30° |
| Deep holes (various materials) or drilling stainless steel, titanium alloys, high temperature alloys, nickel alloys, very high strength materials, tool steels | 118° Split point or crankshaft drill point. | Lip relief angle 9° Chisel edge is entirely eliminated |

^a The lower values of these angle ranges are used for drills of larger diameter, the higher values for the smaller diameters. For drills of diameter less than 1/4-in, the lip relief angle are increased beyond the listed maximum value up to 24°. For soft and free machining materials, 12° to 18° except for diameters less than 1/4 inch, 20° to 26°.

Note: Improperly sharpened twist drills, that is, those with unequal edge length or asymmetrical point angle, will tend to produce holes with poor diameter and directional control.



ANSI Standard Twist Drill Nomenclature

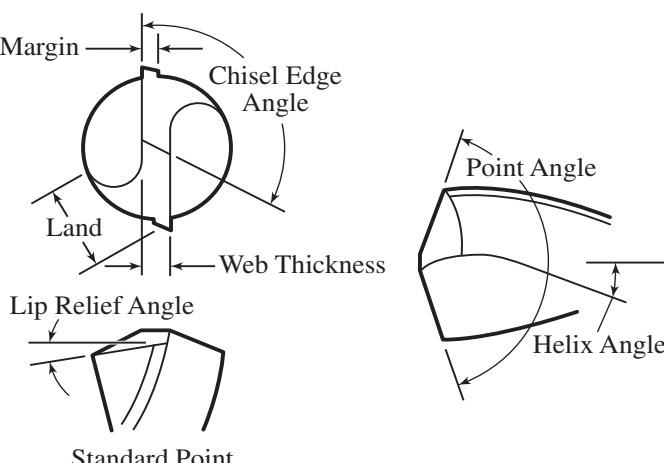


Fig. 1. The principal elements of tool geometry on twist drills.

Table 1. US and Metric Size Commercial Drills

| Fraction No. or Letter | mm | Equivalent | | Fraction No. or Letter | mm | Equivalent | |
|------------------------------|------|------------|-------|------------------------------|------|------------|-------|
| | | Inch | mm | | | Inch | mm |
| 80 | 0.35 | 0.0135 | 0.343 | 57 | 1.10 | 0.0430 | 1.092 |
| | | 0.0138 | 0.350 | | | 0.0433 | 1.100 |
| 79 | 0.38 | 0.0145 | 0.368 | 56 | 1.15 | 0.0453 | 1.150 |
| | | 0.0150 | 0.380 | | | 0.0465 | 1.181 |
| $\frac{1}{64}$ | 0.40 | 0.0156 | 0.396 | $\frac{3}{64}$ | 1.20 | 0.0469 | 1.191 |
| | | 0.0157 | 0.400 | | | 0.0472 | 1.200 |
| 78 | 0.42 | 0.0160 | 0.406 | 55 | 1.25 | 0.0492 | 1.250 |
| | | 0.0165 | 0.420 | | | 0.0512 | 1.300 |
| | | 0.0177 | 0.450 | | | 0.0520 | 1.321 |
| 77 | 0.48 | 0.0180 | 0.457 | 54 | 1.35 | 0.0531 | 1.350 |
| | | 0.0189 | 0.480 | | | 0.0550 | 1.397 |
| | | 0.0197 | 0.500 | | | 0.0551 | 1.400 |
| 76 | | 0.0200 | 0.508 | | 1.40 | 0.0571 | 1.450 |
| 75 | 0.50 | 0.0210 | 0.533 | 53 | 1.50 | 0.0591 | 1.500 |
| | | 0.0217 | 0.550 | | | 0.0595 | 1.511 |
| 74 | 0.60 | 0.0225 | 0.572 | $\frac{1}{16}$ | 1.55 | 0.0610 | 1.550 |
| | | 0.0236 | 0.600 | | | 0.0625 | 1.588 |
| 73 | | 0.0240 | 0.610 | | 1.60 | 0.0630 | 1.600 |
| 72 | 0.65 | 0.0250 | 0.635 | 52 | 1.65 | 0.0635 | 1.613 |
| | | 0.0256 | 0.650 | | | 0.0650 | 1.650 |
| 71 | 0.70 | 0.0260 | 0.660 | 51 | 1.70 | 0.0669 | 1.700 |
| | | 0.0276 | 0.700 | | | 0.0670 | 1.702 |
| 70 | | 0.0280 | 0.711 | | 1.75 | 0.0689 | 1.750 |
| 69 | 0.75 | 0.0292 | 0.742 | 50 | 1.80 | 0.0700 | 1.778 |
| | | 0.0295 | 0.750 | | | 0.0709 | 1.800 |
| 68 | | 0.0310 | 0.787 | | 1.85 | 0.0728 | 1.850 |
| $\frac{1}{32}$ | 0.80 | 0.0312 | 0.792 | 49 | 1.90 | 0.0730 | 1.854 |
| | | 0.0315 | 0.800 | | | 0.0748 | 1.900 |
| 67 | | 0.0320 | 0.813 | 48 | | 0.0760 | 1.930 |
| 66 | 0.85 | 0.0330 | 0.838 | $\frac{5}{64}$ | 1.95 | 0.0768 | 1.950 |
| | | 0.0335 | 0.850 | | | 0.0781 | 1.984 |
| 65 | 0.90 | 0.0350 | 0.889 | 47 | 2.00 | 0.0785 | 1.994 |
| | | 0.0354 | 0.899 | | | 0.0787 | 2.000 |
| 64 | | 0.0360 | 0.914 | | 2.05 | 0.0807 | 2.050 |
| 63 | 0.95 | 0.0370 | 0.940 | 46 | 2.10 | 0.0810 | 2.057 |
| | | 0.0374 | 0.950 | | | 0.0820 | 2.083 |
| 62 | | 0.0380 | 0.965 | | 2.15 | 0.0827 | 2.100 |
| 61 | 1.00 | 0.0390 | 0.991 | 44 | 2.20 | 0.0846 | 2.150 |
| | | 0.0394 | 1.000 | | | 0.0860 | 2.184 |
| 60 | | 0.0400 | 1.016 | | 2.25 | 0.0866 | 2.200 |
| 59 | 1.05 | 0.0410 | 1.041 | 43 | 2.30 | 0.0886 | 2.250 |
| | | 0.0413 | 1.050 | | | 0.0890 | 2.261 |
| 58 | | 0.0420 | 1.067 | | 2.35 | 0.0906 | 2.300 |

Table 1. (Continued) US and Metric Size Commercial Drills

| Fraction No. or Letter | mm | Equivalent | | Fraction No. or Letter | mm | Equivalent | |
|------------------------------|------|------------|-------|------------------------------|------|------------|-------|
| | | Inch | mm | | | Inch | mm |
| 42 | | 0.0935 | 2.375 | 21 | | 0.1590 | 4.039 |
| $\frac{3}{32}$ | | 0.0938 | 2.383 | 20 | | 0.1610 | 4.089 |
| | 2.40 | 0.0945 | 2.400 | | 4.10 | 0.1614 | 4.100 |
| 41 | | 0.0960 | 2.438 | | 4.20 | 0.1654 | 4.200 |
| 40 | 2.46 | 0.0965 | 2.450 | 19 | | 0.1660 | 4.216 |
| | | 0.0980 | 2.489 | | 4.30 | 0.1693 | 4.300 |
| 39 | 2.50 | 0.0984 | 2.500 | 18 | | 0.1695 | 4.305 |
| | | 0.0995 | 2.527 | $\frac{11}{64}$ | | 0.1719 | 4.366 |
| 38 | | 0.1015 | 2.578 | 17 | | 0.1730 | 4.394 |
| | 2.60 | 0.1024 | 2.600 | | 4.40 | 0.1732 | 4.400 |
| 37 | | 0.1040 | 2.642 | 16 | | 0.1770 | 4.496 |
| | 2.70 | 0.1063 | 2.700 | | 4.50 | 0.1772 | 4.500 |
| 36 | | 0.1065 | 2.705 | 15 | | 0.1800 | 4.572 |
| $\frac{7}{64}$ | | 0.1094 | 2.779 | | 4.60 | 0.1811 | 4.600 |
| 35 | | 0.1100 | 2.794 | 14 | | 0.1820 | 4.623 |
| | 2.80 | 0.1102 | 2.800 | 13 | 4.70 | 0.1850 | 4.700 |
| 34 | | 0.1110 | 2.819 | $\frac{3}{16}$ | | 0.1875 | 4.762 |
| 33 | | 0.1130 | 2.870 | 12 | 4.80 | 0.1890 | 4.800 |
| | 2.90 | 0.1142 | 2.900 | 11 | | 0.1910 | 4.851 |
| 32 | | 0.1160 | 2.946 | | 4.90 | 0.1929 | 4.900 |
| | 3.00 | 0.1181 | 3.000 | 10 | | 0.1935 | 4.915 |
| 31 | | 0.1200 | 3.048 | 9 | | 0.1960 | 4.978 |
| | 3.10 | 0.1220 | 3.100 | | 5.00 | 0.1969 | 5.000 |
| $\frac{1}{8}$ | | 0.1250 | 3.175 | 8 | | 0.1990 | 5.054 |
| | 3.20 | 0.1260 | 3.200 | | 5.10 | 0.2008 | 5.100 |
| 30 | | 0.1285 | 3.264 | 7 | | 0.2010 | 5.105 |
| | 3.30 | 0.1299 | 3.300 | $\frac{13}{64}$ | | 0.2031 | 5.159 |
| | | 0.1339 | 3.400 | 6 | | 0.2040 | 5.182 |
| 29 | | 0.1360 | 3.454 | | 5.20 | 0.2047 | 5.200 |
| | 3.50 | 0.1378 | 3.500 | 5 | | 0.2055 | 5.220 |
| 28 | | 0.1405 | 3.569 | | 5.30 | 0.2087 | 5.300 |
| $\frac{5}{64}$ | | 0.1406 | 3.571 | 4 | | 0.2090 | 5.309 |
| | 3.60 | 0.1417 | 3.600 | | 5.40 | 0.2126 | 5.400 |
| 27 | | 0.1440 | 3.658 | 3 | | 0.2130 | 5.410 |
| | 3.70 | 0.1457 | 3.700 | | 5.50 | 0.2165 | 5.500 |
| 26 | | 0.1470 | 3.734 | $\frac{7}{32}$ | | 0.2188 | 5.558 |
| | | 0.1495 | 3.797 | | 5.60 | 0.2205 | 5.600 |
| 25 | | 0.1496 | 3.800 | 2 | | 0.2210 | 5.613 |
| | 3.80 | 0.1520 | 3.861 | | 5.70 | 0.2244 | 5.700 |
| 24 | | 0.1540 | 3.912 | 1 | | 0.2280 | 5.791 |
| $\frac{5}{32}$ | | 0.1562 | 3.967 | | 5.80 | 0.2283 | 5.800 |
| 22 | | 0.1570 | 3.988 | | 5.90 | 0.2323 | 5.900 |
| | 4.00 | 0.1575 | 4.000 | A | | 0.2340 | 5.944 |

Table 1. (Continued) US and Metric Size Commercial Drills

| Fraction No. or Letter | mm | Equivalent | | Fraction No. or Letter | mm | Equivalent | |
|------------------------------|--------|------------|-----------------|------------------------------|--------|------------|--------|
| | | Inch | mm | | | Inch | mm |
| $\frac{15}{64}$ | 0.2344 | 5.954 | P | 8.30 | 0.3230 | 8.204 | |
| | 6.00 | 0.2362 | 6.000 | | 8.40 | 0.3268 | 8.300 |
| B | 0.2380 | 6.045 | $\frac{21}{64}$ | | 8.50 | 0.3281 | 8.334 |
| | 6.10 | 0.2402 | | | 8.60 | 0.3307 | 8.400 |
| C | 0.2420 | 6.147 | Q | | 8.70 | 0.3320 | 8.433 |
| | 6.20 | 0.2441 | | | 8.80 | 0.3346 | 8.500 |
| D | 0.2460 | 6.248 | R | | 8.90 | 0.3386 | 8.600 |
| | 6.30 | 0.2480 | | | 9.00 | 0.3390 | 8.611 |
| E, $\frac{1}{4}$ | 0.2500 | 6.350 | $\frac{11}{32}$ | | 9.10 | 0.3425 | 8.700 |
| | 6.40 | 0.2520 | | | 9.20 | 0.3438 | 8.733 |
| F | 0.2559 | 6.500 | S | | 9.30 | 0.3465 | 8.800 |
| | 6.60 | 0.2570 | | | 9.40 | 0.3480 | 8.839 |
| G | 0.2598 | 6.528 | T | | 9.50 | 0.3504 | 8.900 |
| | 6.70 | 0.2610 | | | 9.60 | 0.3543 | 9.000 |
| H | 0.2638 | 6.700 | $\frac{23}{64}$ | | 9.70 | 0.3580 | 9.093 |
| | 0.2656 | 6.746 | | | 9.80 | 0.3583 | 9.100 |
| I | 0.2660 | 6.756 | U | | 9.90 | 0.3594 | 9.129 |
| | 6.80 | 0.2677 | | | 10.00 | 0.3622 | 9.200 |
| J | 0.2717 | 6.900 | V | | 10.10 | 0.3661 | 9.300 |
| | 7.00 | 0.2720 | | | 10.20 | 0.3680 | 9.347 |
| K | 0.2756 | 7.000 | $\frac{3}{8}$ | | 10.30 | 0.3701 | 9.400 |
| | 7.10 | 0.2770 | | | 10.40 | 0.3740 | 9.500 |
| L | 0.2795 | 7.100 | W | | 10.50 | 0.3750 | 9.525 |
| | 7.20 | 0.2810 | | | 10.60 | 0.3770 | 9.576 |
| M | 0.2812 | 7.142 | $\frac{25}{64}$ | | 10.70 | 0.3780 | 9.600 |
| | 7.30 | 0.2835 | | | 10.80 | 0.3819 | 9.700 |
| N | 0.2874 | 7.300 | X | | 10.90 | 0.3858 | 9.800 |
| | 7.40 | 0.2900 | | | 11.00 | 0.3860 | 9.804 |
| O | 0.2913 | 7.400 | $\frac{27}{64}$ | | 11.10 | 0.3898 | 9.900 |
| | 7.50 | 0.2950 | | | 11.20 | 0.3906 | 9.921 |
| P | 0.2953 | 7.500 | Y | | 11.30 | 0.3937 | 10.000 |
| | 7.60 | 0.2969 | | | 11.40 | 0.3970 | 10.084 |
| Q | 0.2992 | 7.600 | Z | | 11.50 | 0.4016 | 10.200 |
| | 7.70 | 0.3020 | | | 11.60 | 0.4040 | 10.262 |
| R | 0.3031 | 7.671 | $\frac{13}{32}$ | | 11.70 | 0.4062 | 10.317 |
| | 7.80 | 0.3071 | | | 11.80 | 0.4130 | 10.490 |
| S | 0.3110 | 7.900 | $\frac{7}{16}$ | | 11.90 | 0.4134 | 10.500 |
| | 0.3125 | 7.938 | | | 12.00 | 0.4219 | 10.716 |
| T | 0.3150 | 8.000 | V | | 12.10 | 0.4252 | 10.800 |
| | 0.3160 | 8.026 | | | 12.20 | 0.4331 | 11.000 |
| U | 0.3189 | 8.100 | $\frac{9}{16}$ | | 12.30 | 0.4375 | 11.112 |
| | 0.3228 | 8.200 | | | 12.40 | 0.4409 | 11.200 |

Table 1. (Continued) US and Metric Size Commercial Drills

| Fraction No. or Letter | mm | Equivalent | | Fraction No. or Letter | mm | Equivalent | |
|------------------------------|-------|------------|--------|------------------------------|--------|------------|--------|
| | | Inch | mm | | | Inch | mm |
| $\frac{29}{64}$ | 11.50 | 0.4528 | 11.500 | $\frac{43}{64}$ | 17.25 | 0.6719 | 17.066 |
| | | 0.4531 | 11.509 | | | 0.6791 | 17.250 |
| $\frac{15}{32}$ | 11.80 | 0.4646 | 11.800 | $\frac{11}{16}$ | 17.50 | 0.6875 | 17.462 |
| | | 0.4688 | 11.908 | | | 0.6890 | 17.500 |
| $\frac{31}{64}$ | 12.00 | 0.4724 | 12.000 | $\frac{45}{64}$ | 18.00 | 0.7031 | 17.859 |
| | 12.20 | 0.4803 | 12.200 | | | 0.7087 | 18.000 |
| $\frac{3}{8}$ | 12.50 | 0.4844 | 12.304 | $\frac{23}{32}$ | 18.50 | 0.7188 | 18.258 |
| | 12.50 | 0.4921 | 12.500 | | | 0.7283 | 18.500 |
| $\frac{1}{2}$ | 12.80 | 0.5000 | 12.700 | $\frac{47}{64}$ | 19.00 | 0.7344 | 18.654 |
| | 13.00 | 0.5039 | 12.800 | | | 0.7480 | 19.000 |
| $\frac{33}{64}$ | 13.00 | 0.5118 | 13.000 | $\frac{3}{4}$ | 19.50 | 0.7500 | 19.050 |
| | | 0.5156 | 13.096 | | | 0.7656 | 19.446 |
| $\frac{17}{32}$ | 13.20 | 0.5197 | 13.200 | $\frac{25}{32}$ | 20.00 | 0.7677 | 19.500 |
| | | 0.5312 | 13.492 | | | 0.7812 | 19.845 |
| $\frac{35}{64}$ | 13.50 | 0.5315 | 13.500 | $\frac{51}{64}$ | 20.50 | 0.7879 | 20.000 |
| | 13.80 | 0.5433 | 13.800 | | | 0.7969 | 20.241 |
| $\frac{7}{16}$ | 14.00 | 0.5469 | 13.891 | $\frac{13}{16}$ | 21.00 | 0.8071 | 20.500 |
| | 14.25 | 0.5512 | 14.000 | | | 0.8125 | 20.638 |
| $\frac{1}{8}$ | 14.25 | 0.5610 | 14.250 | $\frac{53}{64}$ | 21.00 | 0.8268 | 21.000 |
| | 14.50 | 0.5625 | 14.288 | | | 0.8281 | 21.034 |
| $\frac{37}{64}$ | 14.50 | 0.5709 | 14.500 | $\frac{27}{32}$ | 21.50 | 0.8438 | 21.433 |
| | | 0.5781 | 14.684 | | | 0.8465 | 21.500 |
| $\frac{19}{32}$ | 14.75 | 0.5807 | 14.750 | $\frac{55}{64}$ | 22.00 | 0.8594 | 21.829 |
| | 15.00 | 0.5906 | 15.000 | | | 0.8661 | 22.000 |
| $\frac{39}{64}$ | 15.00 | 0.5938 | 15.083 | $\frac{7}{8}$ | 22.50 | 0.8750 | 22.225 |
| | 15.25 | 0.6004 | 15.250 | | | 0.8858 | 22.500 |
| $\frac{5}{8}$ | 15.25 | 0.6094 | 15.479 | $\frac{57}{64}$ | 23.00 | 0.8906 | 22.621 |
| | 15.50 | 0.6102 | 15.500 | | | 0.9055 | 23.000 |
| $\frac{41}{64}$ | 15.75 | 0.6201 | 15.750 | $\frac{29}{32}$ | 23.50 | 0.9062 | 23.017 |
| | | 0.6250 | 15.875 | | | 0.9219 | 23.416 |
| $\frac{21}{32}$ | 16.00 | 0.6299 | 16.000 | $\frac{15}{16}$ | 24.00 | 0.9252 | 23.500 |
| | 16.25 | 0.6398 | 16.250 | | | 0.9375 | 23.812 |
| $\frac{1}{2}$ | 16.50 | 0.4528 | 11.500 | $\frac{61}{64}$ | 24.50 | 0.9449 | 24.000 |
| | | 0.6406 | 16.271 | | | 0.9531 | 24.209 |
| $\frac{21}{32}$ | 16.50 | 0.6496 | 16.500 | $\frac{31}{32}$ | 25.00 | 0.9646 | 24.500 |
| | | 0.6562 | 16.669 | | | 0.9688 | 24.608 |
| $\frac{63}{64}$ | 16.75 | 0.6594 | 16.750 | $\frac{63}{64}$ | 1.0000 | 0.9843 | 25.000 |
| | 17.00 | 0.6693 | 17.000 | | | 0.9844 | 25.004 |
| | | | | 1 | | 1.0000 | 25.400 |

Table 2. Drilling Difficulties

| | |
|---|--|
| Drill split at the web | Too much feed or insufficient lip clearance at center due to improper grinding. |
| Rapid wear of extreme outer corners of the cutting edges | Speed too high; excessive speed will draw the temper. |
| Chipping or breaking out at the cutting edges | Feed is too heavy or drill ground with too much lip clearance. |
| Checking of high speed drill. | Cold water hitting heated drill. It is equally bad to plunge drill into cold water after the point has been heated in use. |
| Drill Breaks | Insufficient speed when drilling small holes with hand feed increases risk of breakage, especially at the moment the drill is breaking through the further side of the work. Small drills have heavier webs and smaller flutes in proportion to their size than do larger drills, and breakage due to clogging of chips in the flutes is more likely to occur. |
| Drill binds on one side and wears on one side, resulting in a hole larger than the drill. | The point is on center but the cutting edges have been ground at different angles. |
| Drill press spindle wobbles and weaves, resulting in a hole larger than the drill. | Angles of the chisel edge are equal but lips are of different lengths. |
| “Accuracy of drilled holes” | Influenced by many factors, which include: Accuracy of the drill point drill size length and shape of the chisel edge whether or not a bushing is used to guide the drill length of the drill runout of the spindle and the chuck rigidity of the machine tool, workpiece, and the setup the cutting fluid, if any work material |

Note: When drilling holes deeper than three times the diameter of the drill, it is advisable to withdraw the drill at intervals to remove chips and permit coolant to reach the drill tip.

Table 3a. American National Standard Combined Drills and Countersinks—Plain and Bell Types ANSI B94.11M-1993

| Size Designation | Plain Type | | | | | | | |
|------------------|----------------|-------------|----------------|-------------|----------------|-------------|----------------|-------------|
| | Body Diameter | | Drill Diameter | | Drill Length | | Overall Length | |
| | A Inches | Millimeters | D Inches | Millimeters | C Inches | Millimeters | L Inches | Millimeters |
| 00 | $\frac{3}{32}$ | 2.38 | 0.025 | 0.64 | 0.030 | 0.76 | $1\frac{1}{8}$ | 29 |
| 0 | $\frac{3}{32}$ | 2.38 | $\frac{1}{32}$ | 0.79 | 0.038 | 0.97 | $1\frac{1}{8}$ | 29 |
| 1 | $\frac{1}{8}$ | 3.18 | $\frac{3}{64}$ | 1.19 | $\frac{3}{64}$ | 1.19 | $1\frac{1}{4}$ | 32 |
| 2 | $\frac{3}{16}$ | 4.76 | $\frac{5}{64}$ | 1.98 | $\frac{5}{64}$ | 1.98 | $1\frac{7}{8}$ | 48 |
| 3 | $\frac{1}{4}$ | 6.35 | $\frac{7}{64}$ | 2.78 | $\frac{7}{64}$ | 2.78 | 2 | 51 |
| 4 | $\frac{5}{16}$ | 7.94 | $\frac{1}{8}$ | 3.18 | $\frac{1}{8}$ | 3.18 | $2\frac{1}{8}$ | 54 |
| 5 | $\frac{7}{16}$ | 11.11 | $\frac{3}{16}$ | 4.76 | $\frac{3}{16}$ | 4.76 | $2\frac{3}{4}$ | 70 |
| 6 | $\frac{1}{2}$ | 12.70 | $\frac{7}{32}$ | 5.56 | $\frac{7}{32}$ | 5.56 | 3 | 76 |
| 7 | $\frac{5}{8}$ | 15.88 | $\frac{1}{4}$ | 6.35 | $\frac{1}{4}$ | 6.35 | $3\frac{1}{4}$ | 83 |
| 8 | $\frac{3}{4}$ | 19.05 | $\frac{5}{16}$ | 7.94 | $\frac{5}{16}$ | 7.94 | $3\frac{1}{2}$ | 89 |

Table 3b. American National Standard Combined Drills and Countersinks Bell Type ANSI B94.11M-1993

| Size Designation | Bell Type | | | | | | | | | |
|------------------|----------------|-------|----------------|------|---------------|------|----------------|------|----------------|----|
| | Body Diameter | | Drill Diameter | | Bell Diameter | | Drill Length | | Overall Length | |
| | A Inches | mm | D Inches | mm | E Inches | mm | C Inches | mm | L Inches | mm |
| 11 | $\frac{1}{8}$ | 3.18 | $\frac{3}{64}$ | 1.19 | 0.10 | 2.5 | $\frac{3}{64}$ | 1.19 | $1\frac{1}{4}$ | 32 |
| 12 | $\frac{3}{16}$ | 4.76 | $\frac{1}{16}$ | 1.59 | 0.15 | 3.8 | $\frac{1}{16}$ | 1.59 | $1\frac{7}{8}$ | 48 |
| 13 | $\frac{1}{4}$ | 6.35 | $\frac{3}{32}$ | 2.38 | 0.20 | 5.1 | $\frac{3}{32}$ | 2.38 | 2 | 51 |
| 14 | $\frac{5}{16}$ | 7.94 | $\frac{7}{64}$ | 2.78 | 0.25 | 6.4 | $\frac{7}{64}$ | 2.78 | $2\frac{1}{8}$ | 54 |
| 15 | $\frac{7}{16}$ | 11.11 | $\frac{5}{32}$ | 3.97 | 0.35 | 8.9 | $\frac{5}{32}$ | 3.97 | $2\frac{3}{4}$ | 70 |
| 16 | $\frac{1}{2}$ | 12.70 | $\frac{3}{16}$ | 4.76 | 0.40 | 10.2 | $\frac{3}{16}$ | 4.76 | 3 | 76 |
| 17 | $\frac{5}{8}$ | 15.88 | $\frac{7}{32}$ | 5.56 | 0.50 | 12.7 | $\frac{7}{32}$ | 5.56 | $3\frac{1}{4}$ | 83 |
| 18 | $\frac{3}{4}$ | 19.05 | $\frac{1}{4}$ | 6.35 | 0.60 | 15.2 | $\frac{1}{4}$ | 6.35 | $3\frac{1}{2}$ | 89 |

Counterboring.— Counterboring (called spot-facing if the depth is shallow) is the enlargement of a previously formed hole. Counterbores for screw holes are generally made in sets. Each set contains three counterbores: one with the body of the size of the screw head and the pilot the size of the hole to admit the body of the screw; one with the body the size of the head of the screw and the pilot the size of the tap drill; and the third with the body the size of the body of the screw and the pilot the size of the tap drill. Counterbores are usually provided with helical flutes to provide positive effective rake on the cutting edges. The four flutes are so positioned that the end teeth cut ahead of center to provide a shearing action and eliminate chatter in the cut. Three designs are most common: solid, two-piece, and three-piece. Solid designs have the body, cutter, and pilot all in one piece. Two-piece designs have an integral shank and counterbore cutter, with an interchangeable pilot, and provide true concentricity of the cutter diameter with the shank, but allowing use of various pilot diameters. Three-piece counterbores have separate holder, counterbore cutter, and pilot, so that a holder will take any size of counterbore cutter. Each counterbore cutter, in turn, can be fitted with any suitable size diameter of pilot. Counterbores for brass are fluted straight.

Small counterbores are often made with three flutes, but should then have the size plainly stamped on them before fluting, as they cannot afterwards be conveniently measured. The flutes should be deep enough to come below the surface of the pilot. The counterbore should be relieved on the end of the body only, and not on the cylindrical surface. To facilitate the relieving process, a small neck is turned between the guide and the body for clearance. The amount of clearance on the cutting edges is, for general work, from 4 to 5 degrees. The accompanying table gives dimensions for straight shank counterbores.

Table 4. Counterbores with Interchangeable Cutters and Guides

| No. of Holder | No. of Morse Taper Shank | Range of Cutter Diameters, A | Range of Pilot Diameters, B | Total Length, C | Length of Cutter Body, D | Length of Pilot, E | Dia. of Shank, F |
|---------------|--------------------------|--------------------------------------|--------------------------------------|-----------------|--------------------------|--------------------|------------------|
| 1 | 1 or 2 | $\frac{3}{4}\text{--}1\frac{1}{16}$ | $\frac{1}{2}\text{--}\frac{3}{4}$ | $7\frac{1}{4}$ | 1 | $\frac{3}{8}$ | $\frac{3}{4}$ |
| 2 | 2 or 3 | $1\frac{1}{8}\text{--}1\frac{1}{16}$ | $1\frac{1}{16}\text{--}1\frac{1}{8}$ | $9\frac{1}{2}$ | $1\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ |
| 3 | 3 or 4 | $1\frac{5}{8}\text{--}2\frac{1}{16}$ | $\frac{7}{8}\text{--}1\frac{1}{8}$ | $12\frac{1}{2}$ | $1\frac{3}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{8}$ |
| 4 | 4 or 5 | $2\frac{1}{8}\text{--}3\frac{1}{2}$ | $1\text{--}2\frac{1}{8}$ | 15 | $2\frac{1}{4}$ | $1\frac{3}{8}$ | $2\frac{1}{8}$ |

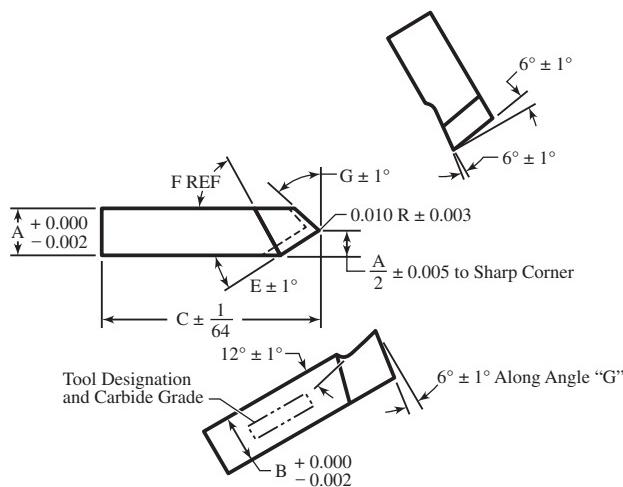
Table 5. Length of Point on Twist Drills and Centering Tools

| Size of Drill | Decimal Equiva- lent | Length of Point when Included Angle =90° | Length of Point when Included Angle =118° | Size of Drill | Decimal Equiva- lent | Length of Point when Included Angle =90° | Length of Point when Included Angle =118° | Size or Dia. of Drill | Decimal Equivalent | Length of Point when Included Angle =90° | Length of Point when Included Angle =118° | Dia. of Drill | Decimal Equiva- lent | Length of Point when Included Angle =90° | Length of Point when Included Angle =118° |
|---------------------|----------------------------|---|--|---------------------|----------------------------|---|--|-----------------------------|-----------------------|---|--|---------------------|----------------------------|---|--|
| 60 | 0.0400 | 0.020 | 0.012 | 37 | 0.1040 | 0.052 | 0.031 | 14 | 0.1820 | 0.091 | 0.055 | 7/8 | 0.3750 | 0.188 | 0.113 |
| 59 | 0.0410 | 0.021 | 0.012 | 36 | 0.1065 | 0.054 | 0.032 | 13 | 0.1850 | 0.093 | 0.056 | 25/64 | 0.3906 | 0.195 | 0.117 |
| 58 | 0.0420 | 0.021 | 0.013 | 35 | 0.1100 | 0.055 | 0.033 | 12 | 0.1890 | 0.095 | 0.057 | 13/32 | 0.4063 | 0.203 | 0.122 |
| 57 | 0.0430 | 0.022 | 0.013 | 34 | 0.1110 | 0.056 | 0.033 | 11 | 0.1910 | 0.096 | 0.057 | 27/64 | 0.4219 | 0.211 | 0.127 |
| 56 | 0.0465 | 0.023 | 0.014 | 33 | 0.1130 | 0.057 | 0.034 | 10 | 0.1935 | 0.097 | 0.058 | 7/16 | 0.4375 | 0.219 | 0.131 |
| 55 | 0.0520 | 0.026 | 0.016 | 32 | 0.1160 | 0.058 | 0.035 | 9 | 0.1960 | 0.098 | 0.059 | 29/64 | 0.4531 | 0.227 | 0.136 |
| 54 | 0.0550 | 0.028 | 0.017 | 31 | 0.1200 | 0.060 | 0.036 | 8 | 0.1990 | 0.100 | 0.060 | 15/32 | 0.4688 | 0.234 | 0.141 |
| 53 | 0.0595 | 0.030 | 0.018 | 30 | 0.1285 | 0.065 | 0.039 | 7 | 0.2010 | 0.101 | 0.060 | 31/64 | 0.4844 | 0.242 | 0.145 |
| 52 | 0.0635 | 0.032 | 0.019 | 29 | 0.1360 | 0.068 | 0.041 | 6 | 0.2040 | 0.102 | 0.061 | 1/2 | 0.5000 | 0.250 | 0.150 |
| 51 | 0.0670 | 0.034 | 0.020 | 28 | 0.1405 | 0.070 | 0.042 | 5 | 0.2055 | 0.103 | 0.062 | 33/64 | 0.5156 | 0.258 | 0.155 |
| 50 | 0.0700 | 0.035 | 0.021 | 27 | 0.1440 | 0.072 | 0.043 | 4 | 0.2090 | 0.105 | 0.063 | 17/32 | 0.5313 | 0.266 | 0.159 |
| 49 | 0.0730 | 0.037 | 0.022 | 26 | 0.1470 | 0.074 | 0.044 | 3 | 0.2130 | 0.107 | 0.064 | 35/64 | 0.5469 | 0.273 | 0.164 |
| 48 | 0.0760 | 0.038 | 0.023 | 25 | 0.1495 | 0.075 | 0.045 | 2 | 0.2210 | 0.111 | 0.067 | 9/16 | 0.5625 | 0.281 | 0.169 |
| 47 | 0.0785 | 0.040 | 0.024 | 24 | 0.1520 | 0.076 | 0.046 | 1 | 0.2280 | 0.114 | 0.068 | 37/64 | 0.5781 | 0.289 | 0.173 |
| 46 | 0.0810 | 0.041 | 0.024 | 23 | 0.1540 | 0.077 | 0.046 | 15/64 | 0.2344 | 0.117 | 0.070 | 19/32 | 0.5938 | 0.297 | 0.178 |
| 45 | 0.0820 | 0.041 | 0.025 | 22 | 0.1570 | 0.079 | 0.047 | 1/4 | 0.2500 | 0.125 | 0.075 | 39/64 | 0.6094 | 0.305 | 0.183 |
| 44 | 0.0860 | 0.043 | 0.026 | 21 | 0.1590 | 0.080 | 0.048 | 17/64 | 0.2656 | 0.133 | 0.080 | 5/8 | 0.6250 | 0.313 | 0.188 |
| 43 | 0.0890 | 0.045 | 0.027 | 20 | 0.1610 | 0.081 | 0.048 | 9/32 | 0.2813 | 0.141 | 0.084 | 41/64 | 0.6406 | 0.320 | 0.192 |
| 42 | 0.0935 | 0.047 | 0.028 | 19 | 0.1660 | 0.083 | 0.050 | 19/64 | 0.2969 | 0.148 | 0.089 | 21/32 | 0.6563 | 0.328 | 0.197 |
| 41 | 0.0960 | 0.048 | 0.029 | 18 | 0.1695 | 0.085 | 0.051 | 5/16 | 0.3125 | 0.156 | 0.094 | 43/64 | 0.6719 | 0.336 | 0.202 |
| 40 | 0.0980 | 0.049 | 0.029 | 17 | 0.1730 | 0.087 | 0.052 | 21/64 | 0.3281 | 0.164 | 0.098 | 11/16 | 0.6875 | 0.344 | 0.206 |
| 39 | 0.0995 | 0.050 | 0.030 | 16 | 0.1770 | 0.089 | 0.053 | 11/32 | 0.3438 | 0.171 | 0.103 | 23/32 | 0.7188 | 0.359 | 0.216 |
| 38 | 0.1015 | 0.051 | 0.030 | 15 | 0.1800 | 0.090 | 0.054 | 23/64 | 0.3594 | 0.180 | 0.108 | 3/4 | 0.7500 | 0.375 | 0.225 |

Table 6. Solid Counterbores with Integral Pilot

| Counterbore Diameters | Pilot Diameters | | | Straight Shank Diameter | Overall Length | |
|--------------------------|-----------------|-------|-------|----------------------------|----------------|-------|
| | Nominal | +1/64 | +1/32 | | Short | Long |
| 13/32 | 1/4 | 17/64 | 9/32 | 3/8 | 3 1/2 | 5 1/2 |
| 1/2 | 5/16 | 21/64 | 11/32 | 3/8 | 3 1/2 | 5 1/2 |
| 19/32 | 3/8 | 25/64 | 13/32 | 1/2 | 4 | 6 |
| 11/16 | 7/16 | 29/64 | 15/32 | 1/2 | 4 | 6 |
| 25/32 | 1/2 | 33/64 | 17/32 | 1/2 | 5 | 7 |
| 0.110 | 0.060 | 0.076 | ... | 7/64 | 2 1/2 | ... |
| 0.133 | 0.073 | 0.089 | ... | 1/8 | 2 1/2 | ... |
| 0.155 | 0.086 | 0.102 | ... | 5/32 | 2 1/2 | ... |
| 0.176 | 0.099 | 0.115 | ... | 11/64 | 2 1/2 | ... |
| 0.198 | 0.112 | 0.128 | ... | 3/16 | 2 1/2 | ... |
| 0.220 | 0.125 | 0.141 | ... | 7/32 | 2 1/2 | ... |
| 0.241 | 0.138 | 0.154 | ... | 1/4 | 2 1/2 | ... |
| 0.285 | 0.164 | 0.180 | ... | 9/32 | 2 3/4 | ... |
| 0.327 | 0.190 | 0.206 | ... | 5/16 | 2 3/4 | ... |
| 0.372 | 0.216 | 0.232 | ... | ... | ... | ... |

All dimensions are in inches.

Table 7. American National Standard Solid Carbide Square Boring Tools—Style SSC for 60° Boring Bar and Style SSE for 45° Boring Bar ANSI B212.1-2002, R2007

| Tool Designation | Boring Bar Angle, Deg. from Axis | Shank Dimensions, Inches | | | Side Cutting Edge Angle E, Deg. | End Cutting Edge Angle G, Deg. | Shoulder Angle F, Deg. |
|---------------------|--|--------------------------|-------------|-------------|---------------------------------------|--------------------------------------|------------------------------|
| | | Width A | Height B | Length C | | | |
| SSC-58 | 60 | 5/32 | 9/32 | 1 | 30 | 38 | 60 |
| SSE-58 | 45 | — | — | — | 45 | 53 | 45 |
| SSC-610 | 60 | 3/16 | 3/16 | 1 1/4 | 30 | 38 | 60 |
| SSE-610 | 45 | — | — | — | 45 | 53 | 45 |
| SSC-810 | 60 | 1/4 | 1/4 | 1 1/4 | 30 | 38 | 60 |
| SSE-810 | 45 | — | — | — | 45 | 53 | 45 |
| SSC-1012 | 60 | 5/16 | 5/16 | 1 1/2 | 30 | 38 | 60 |
| SSE-1012 | 45 | — | — | — | 45 | 53 | 45 |

Hand Reamers.—Hand reamers are made with both straight and helical flutes. Helical flutes provide a shearing cut and are especially useful in reaming holes having keyways or grooves, as these are bridged over by the helical flutes, thus preventing binding or chattering. Hand reamers are made in both solid and expansion forms. The American standard dimensions for solid forms are given in the accompanying table. The expansion type is useful whenever, in connection with repair or other work, it is necessary to enlarge a reamed hole by a few thousandths of an inch. The expansion form is split through the fluted section and a slight amount of expansion is obtained by screwing in a tapering plug. The diameter increase may vary from 0.005 to 0.008 inch for reamers up to about 1 inch diameter and from 0.010 to 0.012 inch for diameters between 1 and 2 inches. Hand reamers are tapered slightly on the end to facilitate starting them properly. The actual diameter of the shanks of commercial reamers may be from 0.002 to 0.005 inch under the reamer size. That part of the shank that is squared should be turned smaller in diameter than the shank itself, so that, when applying a wrench, no burr may be raised that may mar the reamed hole if the reamer is passed clear through it.

When fluting reamers, the cutter is so set with relation to the center of the reamer blank that the tooth gets a slight negative rake; that is, the cutter should be set *ahead* of the center, as shown in the illustration accompanying the table giving the amount to set the cutter ahead of the radial line. The amount is so selected that a tangent to the circumference of the reamer at the cutting point makes an angle of approximately 95 degrees with the front face of the cutting edge.

Illustrations of Terms Applying to Reamers

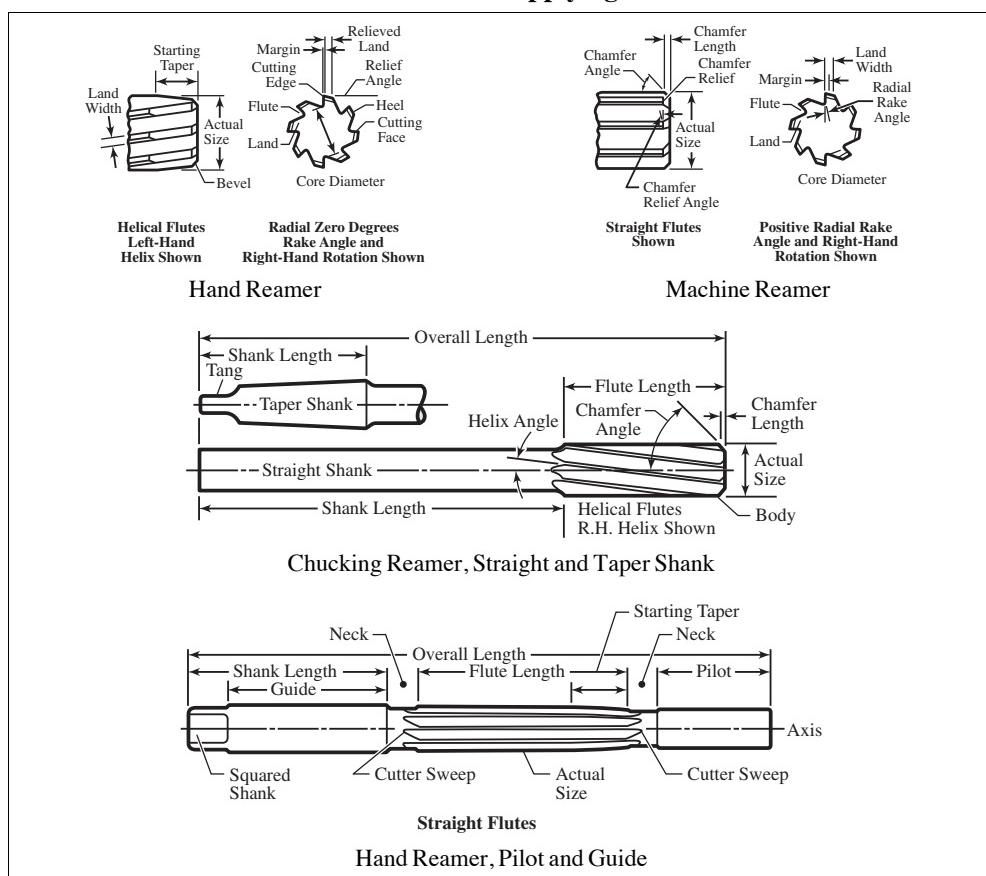
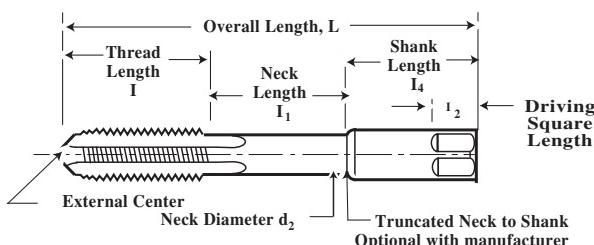
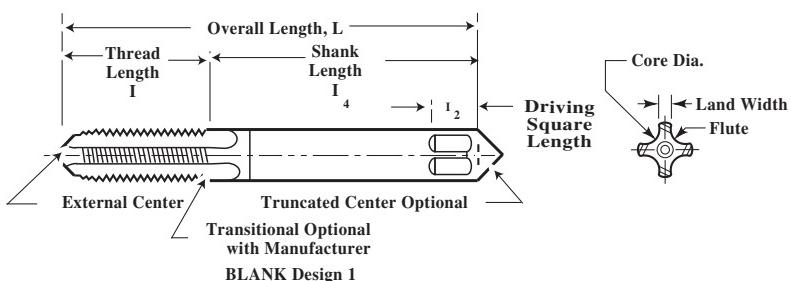


Table 8. Reamer Difficulties

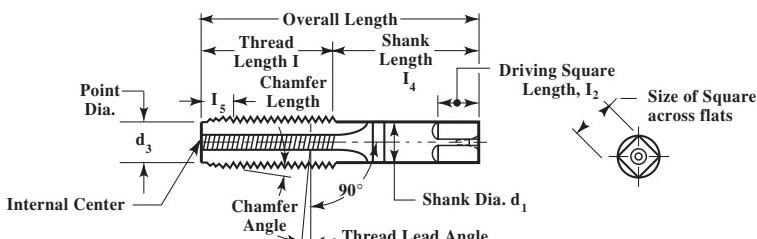
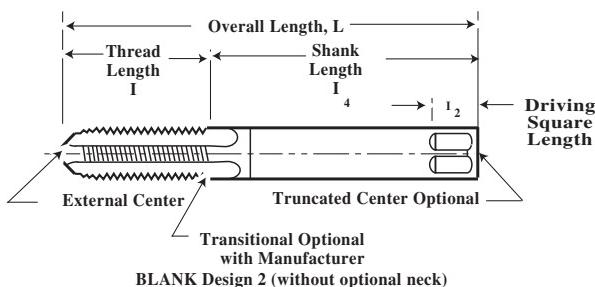
| Problem | Possible Cause | Solution |
|---------------------------------------|--|--|
| Chatter | Lack of rigidity in the machine, spindle, reamer or workpiece. | Reduce the feed. Increase the feed. Chamfer hole before reaming. Reduce clearance angle on the reamers cutting edge. Using a reamer with a pilot and guide bushings. Note: Any amount of chatter may cause carbide-tipped reamer edges to chip, especially as the reamer initially enters the hole. |
| Oversize Holes | Wrong reamer for the workpiece material used. Inadequate workpiece support. Inadequate or worn guide bushings. Loose spindle bearings. Misalignment of the spindles, bushings or workpiece or runout of the spindle or reamer holder. The reamer may be defective due to chamfer runout or runout of the cutting end due to a bent or non-concentric reamer shank. Workpiece material forming a built-up edge on reamer. | Reduce the reamer margin widths to about 0.005 to 0.010 inch. Use hard case surface treatments on high-speed reamers, either alone or in combination with black oxide treatments. Use high-grade finish on the reamer faces, margins, and chamfer relief surfaces. Check and possibly change cutting fluid or coolant. |
| Bell-mouth Holes | Misalignment of the cutting portion of the reamer with respect to the hole. | Provide improved guiding of the reamer by the use of accurate bushings and pilot surfaces. If the reamer is cutting in a vertical position, use a floating holder so that it has both radial and axial movement. |
| Bell-mouth holes in horizontal setups | Misalignment exerts a sideways force on the reamer as it is fed to depth, resulting in a tapered hole. | Shorten the bearing length of the cutting portion of the reamer. The following modifications reduces the length of the reamer tooth that caused the condition. Method 1: Reduce the reamer diameter by 0.010 to 0.030 inch, depending on size and length, behind a short full-diameter section 1/8 to 1 inch long according to length and size, following chamfer, or Method 2: Grind a high back taper 0.008 to 0.015 inch per inch, behind the short full-diameter section. |
| Poor Finish | | Reduce the reamer feed per revolution. Feeds as low as 0.0002 to 0.0005 inch per tooth have been used successfully, but reamer life will be better if the maximum feasible feed is used. The minimum practical amount of stock allowance will often improve finish by reducing the volume of chips and heat generated on the cutting portion of the chamfer. Too small a stock allowance may prevent the reamer teeth from cutting freely and will deflect the work material out of the way and cause rapid reamer wear. Not enough cutting fluid or coolant being applied during reaming. |
| Reamer breaks | Feed too fast. Dull edges | Slow feed Hone edges. |

TAPPING

Tap Terms



BLANK Design 2 with Optional Neck



BLANK Design 3

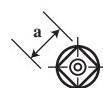
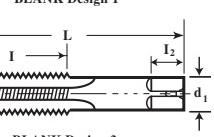
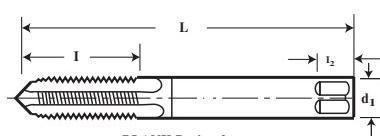
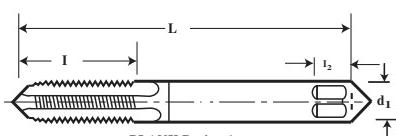


Table 1. Standard Tap Dimensions (Ground and Cut Thread) ASME B94.9-1999

| Nominal Diameter Range, inch | | Nominal Diameter, inch | | Nominal Metric Diameter | | Blank Design No. | Tap Dimensions, inch | | | | |
|------------------------------|-------|---|----------------|-------------------------|--------|------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|-------------------------|
| | | Machine Screw Size No. and Fractional Sizes | Decimal Equiv. | mm | inch | | Overall Length <i>L</i> | Thread Length <i>I</i> | Square Length <i>I</i> ₂ | Shank Diameter <i>d</i> ₁ | Size of Square <i>a</i> |
| Over | To | | | | | | | | | | |
| 0.052 | 0.065 | 0 | (0.0600) | M1.6 | 0.0630 | 1 | 1.63 | 0.31 | 0.19 | 0.141 | 0.110 |
| 0.065 | 0.078 | 1 | (0.0730) | M1.8 | 0.0709 | 1 | 1.69 | 0.38 | 0.19 | 0.141 | 0.110 |
| 0.078 | 0.091 | 2 | (0.0860) | M2.0 | 0.0787 | 1 | 1.75 | 0.44 | 0.19 | 0.141 | 0.110 |
| | | | | M2.2 | 0.0866 | | | | | | |
| 0.091 | 0.104 | 3 | (0.0990) | M2.5 | 0.0984 | 1 | 1.81 | 0.50 | 0.19 | 0.141 | 0.110 |
| 0.104 | 0.117 | 4 | (0.1120) | ... | ... | 1 | 1.88 | 0.56 | 0.19 | 0.141 | 0.110 |
| 0.117 | 0.130 | 5 | (0.1250) | M3.0 | 0.1182 | 1 | 1.94 | 0.63 | 0.19 | 0.141 | 0.110 |
| 0.130 | 0.145 | 6 | (0.1380) | M3.5 | 0.1378 | 1 | 2.00 | 0.69 | 0.19 | 0.141 | 0.110 |
| 0.145 | 0.171 | 8 | (0.1640) | M4.0 | 0.1575 | 1 | 2.13 | 0.75 | 0.25 | 0.168 | 0.131 |
| 0.171 | 0.197 | 10 | (0.1900) | M4.5 | 0.1772 | 1 | 2.38 | 0.88 | 0.25 | 0.194 | 0.152 |
| | | | | M5 | 0.1969 | | | | | | |
| 0.197 | 0.223 | 12 | (0.2160) | ... | ... | 1 | 2.38 | 0.94 | 0.28 | 0.220 | 0.165 |
| 0.223 | 0.260 | 1/4 | (0.2500) | M6 | 0.2363 | 2 | 2.50 | 1.00 | 0.31 | 0.255 | 0.191 |
| 0.260 | 0.323 | 5/16 | (0.3125) | M7 | 0.2756 | 2 | 2.72 | 1.13 | 0.38 | 0.318 | 0.238 |
| | | | | M8 | 0.3150 | | | | | | |
| 0.323 | 0.395 | 3/8 | (0.3750) | M10 | 0.3937 | 2 | 2.94 | 1.25 | 0.44 | 0.381 | 0.286 |
| 0.395 | 0.448 | 7/16 | (0.4375) | ... | ... | 3 | 3.16 | 1.44 | 0.41 | 0.323 | 0.242 |
| 0.448 | 0.510 | 1/2 | (0.5000) | M12 | 0.4724 | 3 | 3.38 | 1.66 | 0.44 | 0.367 | 0.275 |
| 0.510 | 0.573 | 9/16 | (0.5625) | M14 | 0.5512 | 3 | 3.59 | 1.66 | 0.50 | 0.429 | 0.322 |
| 0.573 | 0.635 | 5/8 | (0.6250) | M16 | 0.6299 | 3 | 3.81 | 1.81 | 0.56 | 0.480 | 0.360 |
| 0.635 | 0.709 | 11/16 | (0.6875) | M18 | 0.7087 | 3 | 4.03 | 1.81 | 0.63 | 0.542 | 0.406 |
| 0.709 | 0.760 | 3/4 | (0.7500) | ... | ... | 3 | 4.25 | 2.00 | 0.69 | 0.590 | 0.442 |
| 0.760 | 0.823 | 13/16 | (0.8125) | M20 | 0.7874 | 3 | 4.47 | 2.00 | 0.69 | 0.652 | 0.489 |
| 0.823 | 0.885 | 7/8 | (0.8750) | M22 | 0.8661 | 3 | 4.69 | 2.22 | 0.75 | 0.697 | 0.523 |

Table 1. Standard Tap Dimensions (Ground and Cut Thread)(Continued) ASME B94.9-1999

| Nominal Diameter Range, inch | | Nominal Diameter, inch | | Nominal Metric Diameter | | Blank Design No. | Tap Dimensions, inch | | | | |
|------------------------------|-------|---|----------------|-------------------------|--------|------------------|----------------------|-------------------|---------------------|----------------------|--------------------|
| | | Machine Screw Size No. and Fractional Sizes | Decimal Equiv. | mm | inch | | Overall Length L | Thread Length I | Square Length I_2 | Shank Diameter d_I | Size of Square a |
| Over | To | | | | | | | | | | |
| 0.885 | 0.948 | 15/16 | (0.9375) | M24 | 0.9449 | 3 | 4.91 | 2.22 | 0.75 | 0.760 | 0.570 |
| 0.948 | 1.010 | 1 | (1.0000) | M25 | 0.9843 | 3 | 5.13 | 2.50 | 0.81 | 0.800 | 0.600 |
| 1.010 | 1.073 | 1 1/16 | (1.0625) | M27 | 1.0630 | 3 | 5.13 | 2.50 | 0.88 | 0.896 | 0.672 |
| 1.073 | 1.135 | 1 1/8 | (1.1250) | ... | ... | 3 | 5.44 | 2.56 | 0.88 | 0.896 | 0.672 |
| 1.135 | 1.198 | 1 3/16 | (1.1875) | M30 | 1.1811 | 3 | 5.44 | 2.56 | 1.00 | 1.021 | 0.766 |
| 1.198 | 1.260 | 1 1/4 | (1.2500) | ... | ... | 3 | 5.75 | 2.56 | 1.00 | 1.021 | 0.766 |
| 1.260 | 1.323 | 1 5/16 | (1.3125) | M33 | 1.2992 | 3 | 5.75 | 2.56 | 1.06 | 1.108 | 0.831 |
| 1.323 | 1.385 | 1 3/8 | (1.3750) | ... | ... | 3 | 6.06 | 3.00 | 1.06 | 1.108 | 0.831 |
| 1.358 | 1.448 | 1 7/16 | (1.4375) | M36 | 1.4173 | 3 | 6.06 | 3.00 | 1.13 | 1.233 | 0.925 |
| 1.448 | 1.510 | 1 1/2 | (1.5000) | ... | ... | 3 | 6.38 | 3.00 | 1.13 | 1.233 | 0.925 |
| 1.510 | 1.635 | 1 5/8 | (1.6250) | M39 | 1.5353 | 3 | 6.69 | 3.19 | 1.13 | 1.305 | 0.979 |
| 1.635 | 1.760 | 1 3/4 | (1.7500) | M42 | 1.6535 | 3 | 7.00 | 3.19 | 1.25 | 1.430 | 1.072 |
| 1.760 | 1.885 | 1 7/8 | (1.8750) | ... | ... | 3 | 7.31 | 3.56 | 1.25 | 1.519 | 1.139 |
| 1.885 | 2.010 | 2 | (2.0000) | M48 | 1.8898 | 3 | 7.63 | 3.56 | 1.38 | 1.644 | 1.233 |

Tap sizes 0.395 inch and smaller have an external center on the thread end (may be removed on bottom taps). Sizes 0.223 inch and smaller have an external center on the shank end. Sizes 0.224 inch through 0.395 inch have truncated partial cone centers on the shank end (of diameter of shank). Sizes greater than 0.395 inch have internal centers on both the thread and shank ends.

Table 2. General Threading Formulas

| | | | |
|-----------------|--|---------------------------|--|
| Tap Drill Sizes | $S = D_m - 1.0825 \times P \times \% \text{ (Unified Threads)}$ $S = D_m - 1.2990 \times P \times \% \text{ (American Standard Threads)}$ $S = D_m - 1.0825 \times P \times \% \text{ (ISO Metric Threads)}$ | Percentage of Full Thread | $\frac{D_m - S}{1.0825 - P} = \% \text{ of full thread (Unified Threads)}$ |
| | | | $\frac{D_m - S}{1.2990 - P} = \% \text{ of full thread (American Standard Threads)}$ |
| | | | $\frac{D_m - S}{1.0825 - P} = \% \text{ of full thread (ISO Metric Thread)}$ |

Table 3. General Threading Formulas

| | |
|---------------------------------|--|
| Determining Machine Screw Sizes | $N = \frac{D_m - 0.060}{0.013}$ $D_m = N \times 0.013 + 0.060$ |
|---------------------------------|--|

All dimensions in mm

D_m = major diameter; P = pitch; % = percentage of full thread; S = size of selected tap drill; N = number of machine screw

Courtesy of the Society of Manufacturing Engineers

Table 4. Tapping Specific Materials

| Material | Rake Angle, degrees | Speeds ft/min | Lubricant | Comments |
|--|----------------------------|--|--|--|
| Alloys, high temperature, nickel or cobalt base nonferrous | 0-10 | 5-10 | Sulfur-chlorinated mineral lard oil | Nitrided tap or one made from M41, M42, M43, or M44 Steel recommended. Use plug tap having 3-5 chamfered threads. To reduce rubbing of the lands, eccentric or con- eccentric relieved land should be used. To control a continuous chip use a spiral pointed tap for through holes; use low-helix angle spiral fluted taps for blind holes. Oxide coated tap recommended. |
| Aluminum | 8-20 (10-15 recomended) | 90-100 | Heavy duty water soluble oil or light base mineral oil | Spiral pointed tap for through holes; spiral fluted tap for blind holes |
| Brass | 2-7 | 90-100 | 10-20 % lard oil with mineral oil | Use interrupted thread tap to reduce jamming; straight fluted tap for machine tapping. For red brass, yellow brass and similar alloys containing more than 35% zinc, use a fluted tap for hand tapping; spiral pointed or spiral fluted tap for machine tapping. |
| Brass, Naval, leaded and cast | 5-10 | | Soluble oil | Interrupted thread tap used to reduce jamming. Straight fluted tap for machine tapping. |
| Bronze, Phosphor | 5-12 | 30-60 | Soluble oil | |
| Bronze, Manganese | 5-12 | | Light base oil | |
| Bronze, Tobin | 5-8 | | Soluble oil | |
| Copper | 10-18 | | Medium heavy duty mineral lard oil or soluble oil | For beryllium copper and silicon bronzes use a plug type taps, and keep taps as sharp as possible. |
| Iron, Cast (Gray) | 0-3 | 90 for softer grades 30 for harder grades | Dry or soluble oils or chemical emulsions | Microstructure in a single casting can vary in tensile strength. Oxide coated taps are helpful. Straight fluted taps should be used for all applications. |
| Iron, Malleable | 5-8 | 60-90 (ferritic) 40-50 (pearlitic) 30-50 (martensitic) | Soluble oil martensitic: sulfurbase oil | Microstructure tends to be uniform. Standard taps can be used. |
| Iron, Ductile or Nodular | | 15 (martensitic) 60 (ferritic) | Soluble oil | Oxide coated tap recommended |
| Magnesium | 10-20 | 20-50 | 20% lard oil with 80% mineral oil | Use no water due to fire or explosion hazard |
| Monel Metal | 9-12 | 20-25% lard oil mixed with mineral oil, or sulfur base oil. | | |

Table 4. (Continued) Tapping Specific Materials

| Material | Rake Angle, degrees | Speeds ft/min | Lubricant | Comments |
|--|---|--|--|---|
| Plastics, Thermo plastics | 5-8 thermoplastics 0-3 thermosetting | 50; 25 filled material Reduce speeds for deep and blind holes, and when percentage of thread is greater than 65-75%. | Dry or forced air jet | Taps should be of M10, M7, or M1, molybdenum high-speed steel, with finish-ground and polished flutes. Two-flute taps are recommended for holes up to 0.125 inch diameter. Oversize taps may be required to make up for the elastic recovery of the plastics. |
| Rubber, Hard | 0-3 | | Dry or air jet | |
| Steel, Free Machining | | 60-80 | Soluble oil | Sulfur, lead or phosphorus added to improve machinability. Usually standard tap can be used. |
| Steel, High-Tensile Strength (40-55 Rc) | at or near zero | do not exceed 10 | Active sulfur-chlorinated oil | Taps with concentric lands; 6 to 8 chamfered threads on the end to reduce chip load per tooth. Keep chamfer relief to a minimum. Load on tap should be kept to a minimum: use largest possible tap drill size; keep hole depth to a minimum; avoidance of bottoming holes; and, in larger sizes, use fine instead of coarse pitches. Oxide coated or nitrided tap to reduce tap wear. |
| Steel, Low Carbon (up to 0.15 %C) | 5-12 | 40-60 | Sulfur base oil | Spiral pointed taps for through holes Spiral fluted tap for blind holes. Oxide coated tap recommended. |
| Steel, Low Carbon (up to 0.15-0.30% C) | 5-12 | 40-60 | Sulfur base oil | Oxide coated tap recommended for low carbon range. |
| Steel, Medium Carbon, Annealed (0.30-0.60% C) | 5-10 | 30-50 | Sulfur base oil | Cutting speed dependent on C content and heat treatment. Slowly tap higher C, especially if heat treatment produced pearlitic microstructure. A spheroidized microstructure will result in ease of tapping. |
| Steel, Heat Treated, 225-283 Brinell (0.30 to 0.60% C) | 0-8 | 25-35 | Sulfur base oil | |
| Steel, High Carbon (more than 0.6% C) | 0-5 do not exceed | 25-35 | Activated sulfur-chlorinated | Use concentric tap |
| Steel, High Speed | 0-5 | 25-35 | sulfur base oil | |
| Steel, Molybdenum | | 10-35 | sulfur base oil | |
| Steel, Stainless | 8-15 10-15 Austenitic | 10-35 | Ferritic and martensitic: molybdenum disulfide or other sulfur base oil. Austenitic: sulfur-chlorinated mineral lard or heavy duty soluble oils | Ferritic and martensitic: Standard rake angle oxide coated taps are recommended. Austenitic: Use plug tap having 3-5 chamfered threads. To reduce rub |
| Titanium and alloys | 6-10 | 40-10 depends on composition of alloy | Special | Oxide coated taps are recommended to minimize galling and welding. An eccentric or con-eccentric relief land should be used. Taps with interrupted threads are sometimes helpful. Pure Ti is comparatively easy to tap; alloys are difficult. |

Table 5. American National and Unified Coarse and Fine Thread Dimensions and Tap Drill Sizes

| Thread size and threads per inch | Basic major diameter inches | Pitch diameter inches | Root diameter inches | Tap drill for 75% theoretical thread | Decimal equivalent of tap drill inches |
|----------------------------------|-----------------------------|-----------------------|----------------------|--------------------------------------|--|
| 0 × 80 | 0.0600 | 0.0519 | 0.0438 | 3/64" | 0.0469 |
| 1 × 64 | 0.0730 | 0.0629 | 0.0527 | 53 | 0.0595 |
| 1 × 72 | 0.0730 | 0.0640 | 0.055 | 53 | 0.0595 |
| 2 × 56 | 0.0860 | 0.0744 | 0.0628 | 50 | 0.0700 |
| 2 × 64 | 0.0860 | 0.0759 | 0.0657 | 50 | 0.0700 |
| 3 × 48 | 0.0990 | 0.0855 | 0.0719 | 47 | 0.0785 |
| 3 × 56 | 0.0990 | 0.0874 | 0.0758 | 46 | 0.0810 |
| 4 × 40 | 0.1120 | 0.0958 | 0.0795 | 43 | 0.0890 |
| 4 × 48 | 0.1120 | 0.0985 | 0.0849 | 42 | 0.0935 |
| 5 × 40 | 0.1250 | 0.1088 | 0.0925 | 38 | 0.1015 |
| 5 × 44 | 0.1250 | 0.1102 | 0.0955 | 37 | 0.1040 |
| 6 × 32 | 0.1380 | 0.1177 | 0.0974 | 36 | 0.1065 |
| 6 × 40 | 0.1380 | 0.1218 | 0.1055 | 33 | 0.1130 |
| 8 × 32 | 0.1640 | 0.1437 | 0.1234 | 29 | 0.1360 |
| 8 × 36 | 0.1640 | 0.1460 | 0.1279 | 29 | 0.1360 |
| 10 × 24 | 0.1900 | 0.1629 | 0.1359 | 26 | 0.1470 |
| 10 × 32 | 0.1900 | 0.1697 | 0.1494 | 21 | 0.1590 |
| 12 × 24 | 0.2160 | 0.1889 | 0.1619 | 16 | 0.1770 |
| 12 × 28 | 0.2160 | 0.1928 | 0.1696 | 15 | 0.1800 |
| 1/4" × 20 | 0.2500 | 0.2175 | 0.185 | 7 | 0.2010 |
| 1/4" × 28 | 0.2500 | 0.2268 | 0.2036 | 3 | 0.2130 |
| 5/16" × 18 | 0.3125 | 0.2764 | 0.2403 | F | 0.2570 |
| 5/16" × 24 | 0.3125 | 0.2854 | 0.2584 | I | 0.2720 |
| 3/8" × 16 | 0.3750 | 0.3344 | 0.2938 | 5/16" | 0.3125 |
| 3/8" × 24 | 0.3750 | 0.3479 | 0.3209 | Q | 0.332 |
| 7/16" × 14 | 0.4375 | 0.3911 | 0.3447 | U | 0.368 |
| 7/16" × 20 | 0.4375 | 0.4050 | 0.3726 | 25/64" | 0.3906 |
| 1/2" × 13 | 0.5000 | 0.4500 | 0.4001 | 27/64" | 0.4219 |
| 1/2" × 20 | 0.5000 | 0.4675 | 0.4351 | 29/64" | 0.4531 |
| 9/16" × 12 | 0.5625 | 0.5084 | 0.4542 | 31/64" | 0.4844 |
| 9/16" × 18 | 0.5625 | 0.5264 | 0.4903 | 33/64" | 0.5156 |
| 5/8" × 11 | 0.6250 | 0.5660 | 0.5069 | 17/32" | 0.5312 |
| 5/8" × 18 | 0.6250 | 0.5889 | 0.5528 | 37/64" | 0.5781 |
| 3/4" × 10 | 0.7500 | 0.6850 | 0.6201 | 21/32" | 0.6562 |
| 3/4" × 16 | 0.7500 | 0.7094 | 0.6688 | 11/16" | 0.6875 |
| 7/8" × 9 | 0.8750 | 0.8028 | 0.7307 | 49/64" | 0.7656 |
| 7/8" × 14 | 0.8750 | 0.8286 | 0.7822 | 13/16" | 0.8125 |
| 1" × 8 | 1.0000 | 0.9188 | 0.8376 | 7/8" | 0.8750 |
| 1" × 12 | 1.0000 | 0.9459 | 0.8917 | 59/64" | 0.9219 |
| 1-1/8" × 7 | 1.1250 | 1.0322 | 0.9394 | 63/64" | 0.9844 |
| 1-1/8" × 12 | 1.1250 | 1.0709 | 1.0168 | 1-3/64" | 1.0469 |
| 1-1/4" × 7 | 1.2500 | 1.1572 | 1.0644 | 1-7/64" | 1.1094 |
| 1-1/4" × 12 | 1.2500 | 1.1959 | 1.1418 | 1-11/16" | 1.1719 |
| 1-3/8" × 6 | 1.3750 | 1.2667 | 1.1585 | 1-7/32" | 1.2187 |
| 1-3/8" × 12 | 1.3750 | 1.3209 | 1.2668 | 1-19/64" | 1.2969 |
| 1-1/2" × 6 | 1.5000 | 1.3917 | 1.2835 | 1-11/32" | 1.3437 |
| 1-1/2" × 12 | 1.5000 | 1.4459 | 1.3918 | 1-27/64" | 1.4219 |
| 1-3/4" × 5 | 1.7500 | 1.6201 | 1.4902 | 1-9/16" | 1.5625 |
| 2" × 4-1/2 | 2.0000 | 1.8557 | 1.7113 | 1-25/32" | 1.7812 |

Root Diameter = Nominal Diameter - $2(0.75H)$ = Nominal Diameter - $2(0.75 \times 0.866025 \times P)$

Table 6. Tap Drill Sizes for Threads of American National Form

| Screw Thread | | Commercial Tap Drills ^a | | Screw Thread | | Commercial Tap Drills ^a | |
|---------------------|------------|------------------------------------|----------------|---------------------|------------|------------------------------------|----------------|
| Outside Diam. Pitch | Root Diam. | Size or Number | Decimal Equiv. | Outside Diam. Pitch | Root Diam. | Size or Number | Decimal Equiv. |
| 1/16-64 | 0.0422 | 3/64 | 0.0469 | 27 | 0.4519 | 15/32 | 0.4687 |
| 72 | 0.0445 | 3/64 | 0.0469 | 1/16-12 | 0.4542 | 31/64 | 0.4844 |
| 5/64-60 | 0.0563 | 1/16 | 0.0625 | 18 | 0.4903 | 33/64 | 0.5156 |
| 72 | 0.0601 | 52 | 0.0635 | 27 | 0.5144 | 17/32 | 0.5312 |
| 3/32-48 | 0.0667 | 49 | 0.0730 | 5/8-11 | 0.5069 | 17/32 | 0.5312 |
| 50 | 0.0678 | 49 | 0.0730 | 12 | 0.5168 | 35/64 | 0.5469 |
| 7/64-48 | 0.0823 | 43 | 0.0890 | 18 | 0.5528 | 37/64 | 0.5781 |
| 1/8-32 | 0.0844 | 3/32 | 0.0937 | 27 | 0.5769 | 19/32 | 0.5937 |
| 40 | 0.0925 | 38 | 0.1015 | 11/16-11 | 0.5694 | 19/32 | 0.5937 |
| %4-40 | 0.1081 | 32 | 0.1160 | 16 | 0.6063 | 5/8 | 0.6250 |
| 5/32-32 | 0.1157 | 1/8 | 0.1250 | 3/4-10 | 0.6201 | 21/32 | 0.6562 |
| 36 | 0.1202 | 30 | 0.1285 | 12 | 0.6418 | 43/64 | 0.6719 |
| 11/64-32 | 0.1313 | 3/64 | 0.1406 | 16 | 0.6688 | 11/16 | 0.6875 |
| 3/16-24 | 0.1334 | 26 | 0.1470 | 27 | 0.7019 | 23/32 | 0.7187 |
| 32 | 0.1469 | 22 | 0.1570 | 13/16-10 | 0.6826 | 23/32 | 0.7187 |
| 13/64-24 | 0.1490 | 20 | 0.1610 | 5/8-9 | 0.7307 | 49/64 | 0.7656 |
| 7/32-24 | 0.1646 | 16 | 0.1770 | 12 | 0.7668 | 51/64 | 0.7969 |
| 32 | 0.1782 | 12 | 0.1890 | 14 | 0.7822 | 13/16 | 0.8125 |
| 15/64-24 | 0.1806 | 10 | 0.1935 | 18 | 0.8028 | 53/64 | 0.8281 |
| 1/4-20 | 0.1850 | 7 | 0.2010 | 27 | 0.8269 | 27/32 | 0.8437 |
| 24 | 0.1959 | 4 | 0.2090 | 15/16-9 | 0.7932 | 53/64 | 0.8281 |
| 27 | 0.2019 | 3 | 0.2130 | 1-8 | 0.8376 | 7/8 | 0.8750 |
| 28 | 0.2036 | 3 | 0.2130 | 12 | 0.8918 | 59/64 | 0.9219 |
| 32 | 0.2094 | 7/32 | 0.2187 | 14 | 0.9072 | 15/16 | 0.9375 |
| 5/16-18 | 0.2403 | F | 0.2570 | 27 | 0.9519 | 31/32 | 0.9687 |
| 20 | 0.2476 | 17/64 | 0.2656 | 1 1/8-7 | 0.9394 | 63/64 | 0.9844 |
| 24 | 0.2584 | I | 0.2720 | 12 | 1.0168 | 13/64 | 1.0469 |
| 27 | 0.2644 | J | 0.2770 | 1 1/4-7 | 1.0644 | 17/64 | 1.1094 |
| 32 | 0.2719 | 5/32 | 0.2812 | 12 | 1.1418 | 111/64 | 1.1719 |
| 3/8-16 | 0.2938 | 5/16 | 0.3125 | 1 3/8-6 | 1.1585 | 17/32 | 1.2187 |
| 20 | 0.3100 | 2 1/64 | 0.3281 | 12 | 1.2668 | 119/64 | 1.2969 |
| 24 | 0.3209 | Q | 0.3320 | 1 1/2-6 | 1.2835 | 111/32 | 1.3437 |
| 27 | 0.3269 | R | 0.3390 | 12 | 1.3918 | 127/64 | 1.4219 |
| 7/16-14 | 0.3447 | U | 0.3680 | 1 3/8-5 1/2 | 1.3888 | 129/64 | 1.4531 |
| 20 | 0.3726 | 25/64 | 0.3906 | 1 3/4-5 | 1.4902 | 19/16 | 1.5625 |
| 24 | 0.3834 | X | 0.3970 | 1 3/8-5 | 1.6152 | 111/16 | 1.6875 |
| 27 | 0.3894 | Y | 0.4040 | 2-4 1/2 | 1.7113 | 125/32 | 1.7812 |
| 1/2-12 | 0.3918 | 27/64 | 0.4219 | 2 1/8-4 1/2 | 1.8363 | 129/32 | 1.9062 |
| 13 | 0.4001 | 27/64 | 0.4219 | 2 1/4-4 1/2 | 1.9613 | 2 1/32 | 2.0312 |
| 20 | 0.4351 | 27/64 | 0.4531 | 2 3/8-4 | 2.0502 | 2 1/8 | 2.1250 |
| 24 | 0.4459 | 27/64 | 0.4531 | 2 1/2-4 | 2.1752 | 2 1/4 | 2.2500 |

^aThese tap drill diameters allow approximately 75 per cent of a full thread to be produced. For small thread sizes in the first column, the use of drills to produce the larger hole sizes will reduce defects caused by tap problems and breakage.

Table 7. Tap Drills and Clearance Drills for Machine Screws with American National Thread Form

| Size of Screw | | No. of Threads per Inch | Tap Drills | | Clearance Hole Drills | | | | |
|----------------|----------------|------------------------------------|------------------------------------|----------------------------|-----------------------|----------------|-----------------|----------------|--|
| No. or Diam. | Decimal Equiv. | | Drill Size | Decimal Equiv. | Close Fit | | Free Fit | | |
| | | | | | Drill Size | Decimal Equiv. | Drill Size | Decimal Equiv. | |
| 0 | 0.060 | 80 | $\frac{3}{64}$ | 0.0469 | 52 | 0.0635 | 50 | 0.0700 | |
| 1 | 0.073 | 64 72 | 53 53 | 0.0595 0.0595 | 48 | 0.0760 | 46 | 0.0810 | |
| 2 | 0.086 | 56 64 | 50 50 | 0.0700 0.0700 | 43 | 0.0890 | 41 | 0.0960 | |
| 3 | 0.099 | 48 56 | 47 45 | 0.0785 0.0820 | 37 | 0.1040 | 35 | 0.1100 | |
| 4 | 0.112 | 36 ^a 40 48 | 44 43 42 | 0.0860 0.0890 0.0935 | 32 | 0.1160 | 30 | 0.1285 | |
| 5 | 0.125 | 40 44 | 38 37 | 0.1015 0.1040 | 30 | 0.1285 | 29 | 0.1360 | |
| 6 | 0.138 | 32 40 | 36 33 | 0.1065 0.1130 | 27 | 0.1440 | 25 | 0.1495 | |
| 8 | 0.164 | 32 36 | 29 29 | 0.1360 0.1360 | 18 | 0.1695 | 16 | 0.1770 | |
| 10 | 0.190 | 24 32 | 25 21 | 0.1495 0.1590 | 9 | 0.1960 | 7 | 0.2010 | |
| 12 | 0.216 | 24 28 | 16 14 | 0.1770 0.1820 | 2 | 0.2210 | 1 | 0.2280 | |
| 14 | 0.242 | 20 ^a 24 ^a | 10 7 | 0.1935 0.2010 | D | 0.2460 | F | 0.2570 | |
| $\frac{1}{4}$ | 0.250 | 20 28 | 7 3 | 0.2010 0.2130 | F | 0.2570 | H | 0.2660 | |
| $\frac{5}{16}$ | 0.3125 | 18 24 | F I | 0.2570 0.2720 | P | 0.3230 | Q | 0.3320 | |
| $\frac{3}{8}$ | 0.375 | 16 24 | $\frac{5}{16}$ Q | 0.3125 0.3320 | W | 0.3860 | X | 0.3970 | |
| $\frac{7}{16}$ | 0.4375 | 14 20 | U $\frac{25}{64}$ | 0.3680 0.3906 | $\frac{29}{64}$ | 0.4531 | $\frac{15}{32}$ | 0.4687 | |
| $\frac{1}{2}$ | 0.500 | 13 20 | $\frac{27}{64}$ $\frac{29}{64}$ | 0.4219 0.4531 | $\frac{33}{64}$ | 0.5156 | $\frac{17}{32}$ | 0.5312 | |

^aThese screws are not in the American Standard but are from the former A.S.M.E. Standard.

Table 8. Tap Drills for Pipe Taps

| Size of Tap | Drills for-Briggs Pipe Taps | Drills for-Whitworth Pipe Taps | Size of Tap | Drills for-Briggs Pipe-Taps | Drills for-Whitworth Pipe Taps | Size of Tap | Drills for-Briggs Pipe-Taps | Drills for-Whitworth Pipe Taps |
|---------------|-----------------------------|--------------------------------|----------------|-----------------------------|--------------------------------|----------------|-----------------------------|--------------------------------|
| $\frac{1}{8}$ | $1\frac{1}{32}$ | $\frac{5}{16}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{15}{32}$ | $3\frac{1}{4}$ | ... | $3\frac{1}{2}$ |
| $\frac{1}{4}$ | $\frac{7}{16}$ | $2\frac{7}{64}$ | $1\frac{1}{2}$ | $1\frac{23}{32}$ | $1\frac{25}{32}$ | $3\frac{1}{2}$ | $3\frac{3}{4}$ | $3\frac{3}{4}$ |
| $\frac{3}{8}$ | $1\frac{9}{32}$ | $\frac{9}{16}$ | $1\frac{3}{4}$ | ... | $1\frac{15}{16}$ | $3\frac{3}{4}$ | ... | 4 |
| $\frac{1}{2}$ | $2\frac{9}{32}$ | $1\frac{1}{16}$ | 2 | $2\frac{3}{16}$ | $2\frac{5}{32}$ | 4 | $4\frac{1}{4}$ | $4\frac{1}{4}$ |
| $\frac{5}{8}$ | ... | $2\frac{5}{32}$ | $2\frac{1}{4}$ | ... | $2\frac{13}{32}$ | $4\frac{1}{2}$ | $4\frac{3}{4}$ | $4\frac{3}{4}$ |
| $\frac{3}{4}$ | $1\frac{5}{16}$ | $2\frac{9}{32}$ | $2\frac{1}{2}$ | $2\frac{5}{8}$ | $2\frac{25}{32}$ | 5 | $5\frac{5}{16}$ | $5\frac{1}{4}$ |
| $\frac{7}{8}$ | ... | $1\frac{1}{16}$ | $2\frac{3}{4}$ | ... | $3\frac{1}{32}$ | $5\frac{1}{2}$ | ... | $5\frac{3}{4}$ |
| 1 | $1\frac{9}{32}$ | $1\frac{1}{8}$ | 3 | $3\frac{1}{4}$ | $3\frac{9}{32}$ | 6 | $6\frac{3}{8}$ | $6\frac{1}{4}$ |

All dimensions are in inches.

To secure the best results, the hole should be reamed before tapping with a reamer having a taper of $\frac{3}{4}$ inch per foot.

Table 9. British Standard Tapping Drill Sizes for ISO Metric Coarse Pitch Series Threads BS 1157:2004

| Nominal Size and Thread | Standard Drill Sizes ^a | | | | Nominal Size and Thread Diam. | Standard Drill Sizes ^a | | | | |
|-------------------------|-----------------------------------|--|-------------|--|-------------------------------|-----------------------------------|--|-------------|--|--|
| | Recommended | | Alternative | | | Recommended | | Alternative | | |
| | Size | Theoretical Radial Engagement with Ext. Thread (Percent) | Size | Theoretical Radial Engagement with Ext. Thread (Percent) | | Size | Theoretical Radial Engagement with Ext. Thread (Percent) | Size | Theoretical Radial Engagement with Ext. Thread (Percent) | |
| M 1 | 0.75 | 81.5 | 0.78 | 71.7 | M 12 | 10.20 | 83.7 | 10.40 | 74.5 ^b | |
| M 1.1 | 0.85 | 81.5 | 0.88 | 71.7 | M 14 | 12.00 | 81.5 | 12.20 | 73.4 ^b | |
| M 1.2 | 0.95 | 81.5 | 0.98 | 71.7 | M 16 | 14.00 | 81.5 | 14.25 | 71.3 ^c | |
| M 1.4 | 1.10 | 81.5 | 1.15 | 67.9 | M 18 | 15.50 | 81.5 | 15.75 | 73.4 ^c | |
| M 1.6 | 1.25 | 81.5 | 1.30 | 69.9 | M 20 | 17.50 | 81.5 | 17.75 | 73.4 ^c | |
| M 1.8 | 1.45 | 81.5 | 1.50 | 69.9 | M 22 | 19.50 | 81.5 | 19.75 | 73.4 ^c | |
| M 2 | 1.60 | 81.5 | 1.65 | 71.3 | M 24 | 21.00 | 81.5 | 21.25 | 74.7 ^b | |
| M 2.2 | 1.75 | 81.5 | 1.80 | 72.5 | M 27 | 24.00 | 81.5 | 24.25 | 74.7 ^b | |
| M 2.5 | 2.05 | 81.5 | 2.10 | 72.5 | M 30 | 26.50 | 81.5 | 26.75 | 75.7 ^b | |
| M 3 | 2.50 | 81.5 | 2.55 | 73.4 | M 33 | 29.50 | 81.5 | 29.75 | 75.7 ^b | |
| M 3.5 | 2.90 | 81.5 | 2.95 | 74.7 | M 36 | 32.00 | 81.5 | ... | ... | |
| M 4 | 3.30 | 81.5 | 3.40 | 69.9 ^b | M 39 | 35.00 | 81.5 | ... | ... | |
| M 4.5 | 3.70 | 86.8 | 3.80 | 76.1 | M 42 | 37.50 | 81.5 | ... | ... | |
| M 5 | 4.20 | 81.5 | 4.30 | 71.3 ^b | M 45 | 40.50 | 81.5 | ... | ... | |
| M 6 | 5.00 | 81.5 | 5.10 | 73.4 | M 48 | 43.00 | 81.5 | ... | ... | |
| M 7 | 6.00 | 81.5 | 6.10 | 73.4 | M 52 | 47.00 | 81.5 | ... | ... | |
| M 8 | 6.80 | 78.5 | 6.90 | 71.7 ^b | M 56 | 50.50 | 81.5 | ... | ... | |
| M 9 | 7.80 | 78.5 | 7.90 | 71.7 ^b | M 60 | 54.50 | 81.5 | ... | ... | |
| M 10 | 8.50 | 81.5 | 8.60 | 76.1 | M 64 | 58.00 | 81.5 | ... | ... | |
| M 11 | 9.50 | 81.5 | 9.60 | 76.1 | M 68 | 62.00 | 81.5 | ... | ... | |

^aThese tapping drill sizes are for fluted taps only.

^bFor tolerance class 6H and 7H threads only.

^cFor tolerance class 7H threads only.

Drill sizes are given in millimeters.

Table 10. Tap Drill or Core Hole Sizes for Cold Form Tapping ISO Metric Threads

| Nominal Size of Tap | Pitch | Recommended Tap Drill Size | Nominal Size of Tap | Pitch | Recommended Tap Drill Size |
|---------------------|---------|----------------------------|---------------------|---------|----------------------------|
| 1.6 mm | 0.35 mm | 1.45 mm | 4.0 mm | 0.70 mm | 3.7 mm |
| 1.8 mm | 0.35 mm | 1.65 mm | 4.5 mm | 0.75 mm | 4.2 mm ^a |
| 2.0 mm | 0.40 mm | 1.8 mm | 5.0 mm | 0.80 mm | 4.6 mm |
| 2.2 mm. | 0.45 mm | 2.0 mm | 6.0 mm | 1.00 mm | 5.6 mm ^a |
| 2.5 mm | 0.45 mm | 2.3 mm | 7.0 mm | 1.00 mm | 6.5 mm |
| 3.0 mm | 0.50 mm | 2.8 mm ^a | 8.0 mm | 1.25 mm | 7.4 mm |
| 3.5 mm | 0.60 mm | 3.2 mm | 10.0 mm | 1.50 mm | 9.3 mm |

^aThese diameters are the nearest stocked drill sizes and not the theoretical hole size, and may not produce 60 to 75 per cent full thread.

The sizes are calculated to provide 60 to 75 per cent of full thread.

SPEEDS AND FEEDS

Table 1. Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Plain Carbon and Alloy Steels

| Material AISI and SAE Steels | Hardness HB ^a | Material Condition | Cutting Speed, fpm HSS | | | |
|---|-----------------------------|-----------------------|------------------------|---------|----------|---------|
| | | | Turning | Milling | Drilling | Reaming |
| Free Machining Plain Carbon Steels (Resulfurized) | | | | | | |
| 1212, 1213, 1215 | 100-150 | HR, A | 150 | 140 | 120 | 80 |
| | 150-200 | CD | 160 | 130 | 125 | 80 |
| 1108, 1109, 1115, 1117, 1118, 1120, 1126, 1211 | 100-150 | HR, A | 130 | 130 | 110 | 75 |
| | 150-200 | CD | 120 | 115 | 120 | 80 |
| 1132, 1137, 1139, 1140, 1144, 1146, 1151 | 175-225 | HR, A, N, CD | 120 | 115 | 100 | 65 |
| | 275-325 | Q and T | 75 | 70 | 70 | 45 |
| | 325-375 | Q and T | 50 | 45 | 45 | 30 |
| | 375-425 | Q and T | 40 | 35 | 35 | 20 |
| Free Machining Plain Carbon Steels (Leaded) | | | | | | |
| 11L17, 11L18, 12L13, 12L14 | 100-150 | HR, A, N, CD | 140 | 140 | 130 | 85 |
| | 150-200 | HR, A, N, CD | 145 | 130 | 120 | 80 |
| | 200-250 | N, CD | 110 | 110 | 90 | 60 |
| Plain Carbon Steels | | | | | | |
| 1006, 1008, 1009, 1010, 1012, 1015, 1016, 1017, 1018, 1019, 1020, 1021, 1022, 1023, 1024, 1025, 1026, 1513, 1514 | 100-125 | HR, A, N, CD | 120 | 110 | 100 | 65 |
| | 125-175 | HR, A, N, CD | 110 | 110 | 90 | 60 |
| | 175-225 | HR, N, CD | 90 | 90 | 70 | 45 |
| | 225-275 | CD | 70 | 65 | 60 | 40 |
| 1027, 1030, 1033, 1035, 1036, 1037, 1038, 1039, 1040, 1041, 1042, 1043, 1045, 1046, 1048, 1049, 1050, 1052, 1152, 1524, 1526, 1527, 1541 | 125-175 | HR, A, N, CD | 100 | 100 | 90 | 60 |
| | 175-225 | HR, A, N, CD | 85 | 85 | 75 | 50 |
| | 225-275 | N, CD, Q and T | 70 | 70 | 60 | 40 |
| | 275-325 | Q and T | 60 | 55 | 50 | 30 |
| | 325-375 | Q and T | 40 | 35 | 35 | 20 |
| | 375-425 | Q and T | 30 | 25 | 25 | 15 |
| 1055, 1060, 1064, 1065, 1070, 1074, 1078, 1080, 1084, 1086, 1090, 1095, 1548, 1551, 1552, 1561, 1566 | 125-175 | HR, A, N, CD | 100 | 90 | 85 | 55 |
| | 175-225 | HR, A, N, CD | 80 | 75 | 70 | 45 |
| | 225-275 | N, CD, Q and T | 65 | 60 | 50 | 30 |
| | 275-325 | Q and T | 50 | 45 | 40 | 25 |
| | 325-375 | Q and T | 35 | 30 | 30 | 20 |
| | 375-425 | Q and T | 30 | 15 | 15 | 10 |
| Free Machining Alloy Steels (Resulfurized) | | | | | | |
| 4140, 4150 | 175-200 | HR, A, N, CD | 110 | 100 | 90 | 60 |
| | 200-250 | HR, N, CD | 90 | 90 | 80 | 50 |
| | 250-300 | Q and T | 65 | 60 | 55 | 30 |
| | 300-375 | Q and T | 50 | 45 | 40 | 25 |
| | 375-425 | Q and T | 40 | 35 | 30 | 15 |
| Free Machining Alloy Steels (Leaded) | | | | | | |
| 41L30, 41L40, 41L47, 41L50, 43L47, 51L32, 52L100, 86L20, 86L40 | 150-200 | HR, A, N, CD | 120 | 115 | 100 | 65 |
| | 200-250 | HR, N, CD | 100 | 95 | 90 | 60 |
| | 250-300 | Q and T | 75 | 70 | 65 | 40 |
| | 300-375 | Q and T | 55 | 50 | 45 | 30 |
| | 375-425 | Q and T | 50 | 40 | 30 | 15 |

Table 1. (Continued) Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Plain Carbon and Alloy Steels

| Material AISI and SAE Steels | Hardness HB ^a | Material Condition | Cutting Speed, fpm HSS | | | |
|--|-----------------------------|-----------------------|------------------------|---------|----------|---------|
| | | | Turning | Milling | Drilling | Reaming |
| Alloy Steels | | | | | | |
| 4012, 4023, 4024, 4028, 4118, 4320, 4419, 4422, 4427, 4615, 4620, 4621, 4626, 4718, 4720, 4815, 4817, 4820, 5015, 5117, 5120, 6118, 8115, 8615, 8617, 8620, 8622, 8625, 8627, 8720, 8822, 94B17 | 125-175 | HR, A, N, CD | 100 | 100 | 85 | 55 |
| | 175-225 | HR, A, N, CD | 90 | 90 | 70 | 45 |
| | 225-275 | CD, N, Q and T | 70 | 60 | 55 | 35 |
| | 275-325 | Q and T | 60 | 50 | 50 | 30 |
| | 325-375 | Q and T | 50 | 40 | 35 | 25 |
| | 375-425 | Q and T | 35 | 25 | 25 | 15 |
| 1330, 1335, 1340, 1345, 4032, 4037, 4042, 4047, 4130, 4135, 4137, 4140, 4142, 4145, 4147, 4150, 4161, 4337, 4340, 50B44, 50B46, 50B50, 50B60, 5130, 5132, 5140, 5145, 5147, 5150, 5160, 51B60, 6150, 81B45, 8630, 8635, 8637, 8640, 8642, 8645, 8650, 8655, 8660, 8740, 9254, 9255, 9260, 9262, 94B30 | 175-225 | HR, A, N, CD | 85 | 75 | 75 | 50 |
| | 225-275 | N, CD, Q and T | 70 | 60 | 60 | 40 |
| | 275-325 | N, Q and T | 60 | 50 | 45 | 30 |
| | 325-375 | N, Q and T | 40 | 35 | 30 | 15 |
| | 375-425 | Q and T | 30 | 20 | 20 | 15 |
| | 175-225 | HR, A, CD | 70 | 65 | 60 | 40 |
| E51100, E52100 | 225-275 | N, CD, Q and T | 65 | 60 | 50 | 30 |
| | 275-325 | N, Q and T | 50 | 40 | 35 | 25 |
| | 325-375 | N, Q and T | 30 | 30 | 30 | 20 |
| | 375-425 | Q and T | 20 | 20 | 20 | 10 |
| Ultra High Strength Steels (Not AISI) | | | | | | |
| AMS 6421 (98B37 Mod.), AMS 6422 (98BV40), AMS 6424, AMS 6427, AMS 6428, AMS 6430, AMS 6432, AMS 6433, AMS 6434, AMS 6436, AMS 6442, 300M, D6ac | 220-300 | A | 65 | 60 | 50 | 30 |
| | 300-350 | N | 50 | 45 | 35 | 20 |
| | 350-400 | N | 35 | 20 | 20 | 10 |
| | 43-48 HRC | Q and T | 25 | ... | ... | ... |
| | 48-52 HRC | Q and T | 10 | ... | ... | ... |
| | 50-52 HRC | Q and T | 10 | ... | ... | ... |
| Maraging Steels (Not AISI) | | | | | | |
| 18% Ni Grade 200, 18% Ni Grade 250, 18% Ni Grade 300, 18% Ni Grade 350 | 250-325 | A | 60 | 50 | 50 | 30 |
| | 50-52 HRC | Maraged | 10 | ... | ... | ... |
| Nitriding Steels (Not AISI) | | | | | | |
| Nitr alloy 125, Nitr alloy 135, Nitr alloy 135 Mod., Nitr alloy 225, Nitr alloy 230, Nitr alloy N, Nitr alloy EZ, Nitrex I | 200-250 | A | 70 | 60 | 60 | 40 |
| | 300-350 | N, Q and T | 30 | 25 | 35 | 20 |

^a Abbreviations designate: HR, hot rolled; CD, cold drawn; A, annealed; N, normalized; Q and T, quenched and tempered; and HB, Brinell hardness number.

Speeds for turning based on a feed rate of 0.012 inch per revolution and a depth of cut of 0.125 inch.

Table 2. Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Ferrous Cast Metals

| Material | Hardness HB ^a | Material Condition | Cutting Speed, fpm HSS | | | |
|--|---|--|----------------------------|-----------------------------------|----------------------------|----------------------------|
| | | | Turning | Milling | Drilling | Reaming |
| Gray Cast Iron | | | | | | |
| ASTM Class 20 | 120-150 | A | 120 | 100 | 100 | 65 |
| ASTM Class 25 | 160-200 | AC | 90 | 80 | 90 | 60 |
| ASTM Class 30, 35, and 40 | 190-220 | AC | 80 | 70 | 80 | 55 |
| ASTM Class 45 and 50 | 220-260 | AC | 60 | 50 | 60 | 40 |
| ASTM Class 55 and 60 | 250-320 | AC, HT | 35 | 30 | 30 | 20 |
| ASTM Type 1, 1b, 5 (Ni Resist) | 100-215 | AC | 70 | 50 | 50 | 30 |
| ASTM Type 2, 3, 6 (Ni Resist) | 120-175 | AC | 65 | 40 | 40 | 25 |
| ASTM Type 2b, 4 (Ni Resist) | 150-250 | AC | 50 | 30 | 30 | 20 |
| Malleable Iron | | | | | | |
| (Ferritic), 32510, 35018 | 110-160 | MHT | 130 | 110 | 110 | 75 |
| (Pearlitic), 40010, 43010, 45006, 45008, 48005, 50005 | 160-200 200-240 | MHT MHT | 95 75 | 80 65 | 80 70 | 55 45 |
| (Martensitic), 53004, 60003, 60004 | 200-255 | MHT | 70 | 55 | 55 | 35 |
| (Martensitic), 70002, 70003 | 220-260 | MHT | 60 | 50 | 50 | 30 |
| (Martensitic), 80002 | 240-280 | MHT | 50 | 45 | 45 | 30 |
| (Martensitic), 90001 | 250-320 | MHT | 30 | 25 | 25 | 15 |
| Nodular (Ductile) Iron | | | | | | |
| (Ferritic), 60-40-18, 65-45-12 | 140-190 | A | 100 | 75 | 100 | 65 |
| (Ferritic-Pearlitic), 80-55-06 | 190-225 225-260 | AC AC | 80 65 | 60 50 | 70 50 | 45 30 |
| (Pearlitic-Martensitic), 100-70-03 | 240-300 | HT | 45 | 40 | 40 | 25 |
| (Martensitic), 120-90-02 | 270-330 330-400 | HT HT | 30 15 | 25 — | 25 10 | 15 5 |
| Cast Steels | | | | | | |
| (Low Carbon), 1010, 1020 | 100-150 | AC, A, N | 110 | 100 | 100 | 65 |
| | 125-175 | AC, A, N | 100 | 95 | 90 | 60 |
| (Medium Carbon), 1030, 1040, 1050 | 175-225 225-300 | AC, A, N AC, HT | 90 70 | 80 60 | 70 55 | 45 35 |
| (Low Carbon Alloy), 1320, 2315, 2320, 4110, 4120, 4320, 8020, 8620 | 150-200 200-250 250-300 | AC, A, N AC, A, N AC, HT | 90 80 60 | 85 75 50 | 75 65 50 | 50 40 30 |
| (Medium Carbon Alloy), 1330, 1340, 2325, 2330, 4125, 4130, 4140, 4330, 4340, 8030, 80B30, 8040, 8430, 8440, 8630, 8640, 9525, 9530, 9535 | 175-225 225-250 250-300 300-350 350-400 | AC, A, N AC, A, N AC, HT AC, HT HT | 80 70 55 45 30 | 70 65 50 30 ... 20 | 70 60 45 30 20 | 45 35 30 20 10 |

^a Abbreviations designate: A, annealed; AC, as cast; N, normalized; HT, heat treated; MHT, malleabilizing heat treatment; and HB, Brinell hardness number.

Speeds for turning based on a feed rate of 0.012 inch per revolution and a depth of cut of 0.125 inch.

Table 3. Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Stainless Steels

| Material | Hardness HB ^a | Material Condition | Cutting Speed, fpm HSS | | | |
|---|--|---------------------------------|------------------------|----------------------|----------------------|----------------------|
| | | | Turning | Milling | Drilling | Reaming |
| Free Machining Stainless Steels (Ferritic) | | | | | | |
| 430F, 430F Se | 135-185 | A | 110 | 95 | 90 | 60 |
| (Austenitic), 203EZ, 303, 303Se, 303MA, 303Pb, 303Cu, 303 Plus X | 135-185 225-275 | A CD | 100 80 | 90 75 | 85 70 | 55 45 |
| (Martensitic), 416, 416Se, 416Plus X, 420F, 420FSe, 440F, 440FSe | 135-185 185-240 275-325 375-425 | A A,CD Q and T Q and T | 110 100 60 30 | 95 80 50 20 | 90 70 40 20 | 60 45 25 10 |
| Stainless Steels | | | | | | |
| (Ferritic), 405, 409, 429, 430, 434, 436, 442, 446, 502 | 135-185 | A | 90 | 75 | 65 | 45 |
| (Austenitic), 201, 202, 301, 302, 304, 304L, 305, 308, 321, 347, 348 | 135-185 225-275 | A CD | 75 65 | 60 50 | 55 50 | 35 30 |
| (Austenitic), 302B, 309, 309S, 310, 310S, 314, 316, 316L, 317, 330 | 135-185 | A | 70 | 50 | 50 | 30 |
| (Martensitic), 403, 410, 420, 501 | 135-175 175-225 275-325 375-425 | A A Q and T Q and T | 95 85 55 35 | 75 65 40 25 | 75 65 40 25 | 50 45 25 15 |
| (Martensitic), 414, 431, Greek Ascoloy | 225-275 275-325 375-425 | A Q and T Q and T | 60 50 30 | 55 45 25 | 50 40 25 | 30 25 15 |
| (Martensitic), 440A, 440B, 440C | 225-275 275-325 375-425 | A Q and T Q and T | 55 45 30 | 50 40 20 | 45 40 20 | 30 25 10 |
| (Precipitation Hardening), 15-5PH, 17-4PH, 17-7PH, AF-71, 17-14CuMo, AFC-77, AM-350, AM-355, AM-362, Custom 455, HNM, PH13-8, PH14-8Mo, PH15-7Mo, Stainless W | 150-200 275-325 325-375 375-450 | A H H H | 60 50 40 25 | 60 50 40 25 | 50 45 35 20 | 30 25 20 10 |

^a Abbreviations designate: A, annealed; CD, cold drawn; N, normalized; H, precipitation hardened; Q and T, quenched and tempered; and HB, Brinell hardness number.

Speeds for turning based on a feed rate of 0.012 inch per revolution and a depth of cut of 0.125 inch.

Table 4. Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Tool Steels

| Material Tool Steels (AISI Types) | Hardness HB ^a | Material Condition | Cutting Speed, fpm HSS | | | |
|---|-----------------------------|-----------------------|------------------------|---------|----------|---------|
| | | | Turning | Milling | Drilling | Reaming |
| Water Hardening W1, W2, W5 | 150-200 | A | 100 | 85 | 85 | 55 |
| Shock Resisting S1, S2, S5, S6, S7 | 175-225 | A | 70 | 55 | 50 | 35 |
| Cold Work, Oil Hardening O1, O2, O6, O7 | 175-225 | A | 70 | 50 | 45 | 30 |
| Cold Work, High Carbon High Chromium D2, D3, D4, D5, D7 | 200-250 | A | 45 | 40 | 30 | 20 |
| Cold Work, Air Hardening A2, A3, A8, A9, A10 | 200-250 | A | 70 | 50 | 50 | 35 |
| A4, A6 | 200-250 | A | 55 | 45 | 45 | 30 |
| A7 | 225-275 | A | 45 | 40 | 30 | 20 |
| Hot Work, Chromium Type H10, H11, H12, H13, H14, H19 | 150-200 | A | 80 | 60 | 60 | 40 |
| | 200-250 | A | 65 | 50 | 50 | 30 |
| | 325-375 | Q and T | 50 | 30 | 30 | 20 |
| | 48-50 HRC | Q and T | 20 | ... | ... | ... |
| | 50-52 HRC | Q and T | 10 | ... | ... | ... |
| | 52-54 HRC | Q and T | ... | ... | ... | ... |
| | 54-56 HRC | Q and T | ... | ... | ... | ... |
| Hot Work, Tungsten Type H21, H22, H23, H24, H25, H26 | 150-200 | A | 60 | 55 | 55 | 35 |
| | 200-250 | A | 50 | 45 | 40 | 25 |
| Hot Work, Molybdenum Type H41, H42, H43 | 150-200 | A | 55 | 55 | 45 | 30 |
| | 200-250 | A | 45 | 45 | 35 | 20 |
| Special Purpose, Low Alloy L2, L3, L6 Mold P2, P3, P4, P5, P6 P20, P21 High Speed Steel M1, M2, M6, M10, T1, T2, T6 M3-1, M4, M7, M30, M33, M34, M36, M41, M42, M43, M44, M46, M47, T5, T8 T15, M3-2 | 150-200 | A | 75 | 65 | 60 | 40 |
| | 100-150 | A | 90 | 75 | 75 | 50 |
| | 150-200 | A | 80 | 60 | 60 | 40 |
| | 200-250 | A | 65 | 50 | 45 | 30 |
| | 225-275 | A | 55 | 40 | 35 | 20 |
| | 225-275 | A | 45 | 30 | 25 | 15 |

^a Abbreviations designate: A, annealed; Q and T, quenched and tempered; HB, Brinell hardness number; and HRC, Rockwell C scale hardness number.

Speeds for turning based on a feed rate of 0.012 inch per revolution and a depth of cut of 0.125 inch.

Table 5. Recommended Cutting Speeds in Feet per Minute for Turning, Milling, Drilling and Reaming Light Metals

| Material Light Metals | Material Condition ^a | Cutting Speed, fpm HSS | | | |
|---|------------------------------------|------------------------|---------|----------|---------|
| | | Turning | Milling | Drilling | Reaming |
| All Wrought Aluminum Alloys | CD | 600 | 600 | 400 | 400 |
| | ST and A | 500 | 500 | 350 | 350 |
| All Aluminum Sand and Permanent Mold Casting Alloys | AC | 750 | 750 | 500 | 500 |
| | ST and A | 600 | 600 | 350 | 350 |
| All Aluminum Die Casting Alloys | AC | 125 | 125 | 300 | 300 |
| | ST and A | 100 | 100 | 70 | 70 |
| except Alloys 390.0 and 392.0 | AC | 80 | 80 | 125 | 100 |
| | ST and A | 60 | 60 | 45 | 40 |
| All Wrought Magnesium Alloys | A, CD, ST, and A | 800 | 800 | 500 | 500 |
| All Cast Magnesium Alloys | A, AC, ST, and A | 800 | 800 | 450 | 450 |

^a Abbreviations designate: A, annealed; AC, as cast; CD, cold drawn; ST and A, solution treated as aged.

Table 6. Recommended Cutting Speeds in Feet per Minute for Turning and Drilling Titanium and Titanium Alloys

| Material Titanium and Titanium Alloys | Material Condition ^a | Hardness, HB ^a | Cutting Speed, fpm HSS |
|--|------------------------------------|------------------------------|------------------------------|
| Commercially Pure | | | |
| 99.5 Ti | A | 110-150 | 110 |
| 99.1 Ti, 99.2 Ti | A | 180-240 | 90 |
| 99.0 Ti | A | 250-275 | 70 |
| Low Alloyed | | | |
| 99.5 Ti - 0.15 Pd | A | 110-150 | 100 |
| 99.2 Ti - 0.15 Pd, 98.9 Ti - 0.8 Ni - 0.3 Mo | A | 180-250 | 85 |
| Alpha Alloys and Alpha-Beta Alloys | | | |
| 5Al-2.5 Sn, 8Mn, 2Al-11Sn-5Zr-1Mo, 4Al-3Mo-1V, 5Al-6Sn-2Zr-1Mo, 6Al-2Sn-4Zr-2Mo, 6Al-2Sn-4Zr-6Mo, 6Al-2Sn-4Zr-2Mo-0.25Si | A | 300-350 | 50 |
| 6Al-4V | A | 310-350 | 40 |
| 6Al-6V-2Sn, 7Al-4Mo, 8Al-1Mo-1V | A | 320-370 | 30 |
| 8V-5Fe-1Al | A | 320-380 | 20 |
| 6Al-4V, 6Al-2Sn-4Zr-2Mo, 6Al-2Sn-4Zr-6Mo, 6Al-2Sn-4Zr-2Mo-0.25Si | ST and A | 320-380 | 40 |
| 4Al-3Mo-1V, 6Al-6V-2Sn, 7Al-4Mo | ST and A | 375-420 | 20 |
| 1Al-8V-5Fe | ST and A | 375-440 | 20 |
| Beta Alloys | | | |
| 13V-11Cr-3Al, 8Mo-8V-2Fe-3Al, 3Al-8V-6Cr-4Mo-4Zr, 11.5Mo-6Zr-4.5Sn | A, ST ST and A | 275-350 350-440 | 25 20 |

^a Abbreviations designate: A, annealed; ST, solution treated; ST and A, solution treated as aged; and HB, Brinell hardness number.

Table 7. Recommended Cutting Speeds in Feet per Minute for Turning, Milling and Drilling* Superalloys

| Material Superalloys | Cutting Speed, fpm HSS | | Material Superalloys | Cutting Speed, fpm HSS | |
|---|---------------------------|-----------|-----------------------------------|---------------------------|-----------|
| | Roughing | Finishing | | Roughing | Finishing |
| A-286 | 30-35 | 35-40 | Mar-M200, M246, M421, and M432 | 8-10 | 10-12 |
| AF ₂ -1DA | 8-10 | 10-15 | Mar-M905, and M918 | 15-20 | 20-25 |
| Air Resist 213 | 15-20 | 20-25 | Mar-M302, M322, and M509 | 10-12 | 10-15 |
| Air Resist 13, and 215 | 10-12 | 10-15 | N-12M | 8-12 | 10-15 |
| Astroloy | 5-10 | 5-15 | N-155 | 15-20 | 15-25 |
| B-1900 | 8-10 | 8-10 | Nasa C-W-Re | 10-12 | 10-15 |
| CW-12M | 8-12 | 10-15 | Nimonic 75, and 80 | 15-20 | 20-25 |
| Discalloy | 15-35 | 35-40 | Nimonic 90, and 95 | 10-12 | 12-15 |
| FSH-H14 | 10-12 | 10-15 | Refractaloy 26 | 15-20 | 20-25 |
| GMR-235, and 235D | 8-10 | 8-10 | Rene 41 | 10-15 | 12-20 |
| Hastelloy B, C, G, and X (wrought) | 15-20 | 20-25 | Rene 80, and 95 | 8-10 | 10-15 |
| Hastelloy B, and C (cast) | 8-12 | 10-15 | S-590 | 10-20 | 15-30 |
| Haynes 25, and 188 | 15-20 | 20-25 | S-816 | 10-15 | 15-20 |
| Haynes 36, and 151 | 10-12 | 10-15 | T-D Nickel | 70-80 | 80-100 |
| HS 6, 21, 2, 31(X40), 36, and 151 | 10-12 | 10-15 | Udimet 500, 700, and 710 | 10-15 | 12-20 |
| IN 100, and 738 | 8-10 | 8-10 | Udimet 630 | 10-20 | 20-25 |
| Incoloy 800, 801, and 802 | 30-35 | 35-40 | Unitemp 1753 | 8-10 | 10-15 |
| Incoloy 804, and 825 | 15-20 | 20-25 | V-36 | 10-15 | 15-20 |
| Incoloy 901 | 10-20 | 20-35 | V-57 | 30-35 | 35-40 |
| Inconel 625, 702, 706, 718 (wrought), 721, 722, X750, 751, 901, 600, and 604 | 15-20 | 20-25 | W-545 | 25-35 | 30-40 |
| Inconel 700, and 702 | 10-12 | 12-15 | WI-52 | 10-12 | 10-15 |
| Inconel 713C, and 718 (cast) | 8-10 | 8-10 | Waspaloy | 10-30 | 25-35 |
| J1300 | 15-25 | 20-30 | X-45 | 10-12 | 10-15 |
| J1570 | 15-20 | 20-25 | 16-25-6 | 30-35 | 35-40 |
| M252 (wrought) | 15-20 | 20-25 | 19-9DL | 25-35 | 30-40 |
| M252 (cast) | 8-10 | 8-10 | | | |

* For milling and drilling, use the cutting speeds recommended under roughing.

**Table 8. Cutting Feeds and Speeds for
Turning, Drilling, and Reaming Copper Alloys**

| Group 1 | | | | | |
|---|-----------------------|---------------------------|------------|------------|--|
| Architectural bronze (C38500); Extra-high-headed brass (C35600); Forging brass (C37700); Free-cutting phosphor bronze, B2 (C54400); Free-cutting brass (C36000); Free-cutting Muntz metal (C37000); High-leaded brass (C33200; C34200); High-leaded brass tube (C35300); Leaded commercial bronze (C31400); Leaded naval brass (C48500); Medium-leaded brass (C34000) | | | | | |
| Group 2 | | | | | |
| Aluminum brass, arsenical (C68700); Cartridge brass, 70% (C26000); High-silicon bronze, B (C65500); Admiralty brass (inhibited) (C44300, C44500); Jewelry bronze, 87.5% (C22600); Leaded Muntz metal (C36500, C36800); Leaded nickel silver (C79600); Low brass, 80% (C24000); Low-leaded brass (C33500); Low-silicon bronze, B (C65100); Manganese bronze, A (C67500); Muntz metal, 60% (C28000); Nickel silver, 55-18 (C77000); Red brass, 85% (C23000); Yellow brass (C26800) | | | | | |
| Group 3 | | | | | |
| Aluminum bronze, D (C61400); Beryllium copper (C17000, C17200, C17500); Commercial bronze, 90% (C22000); Copper nickel, 10% (C70600); Copper nickel, 30% (C71500); Electrolytic tough pitch copper (C11000); Guilding, 95% (C21000); Nickel silver, 65-10 (C74500); Nickel silver, 65-12 (C75700); Nickel silver, 65-15 (C75400); Nickel silver, 65-18 (C75200); Oxygen-free copper (C10200); Phosphor bronze, 1.25% (C50200); Phosphor bronze, 10% D (C52400); Phosphor bronze, 5% A (C51000); Phosphor bronze, 8% C (C52100); Phosphorus deoxidized copper (C12200) | | | | | |
| Wrought Alloys Description and UNS Alloy Numbers | Material Condition | Cutting Speed, fpm HSS | | | |
| | | Turning | Drilling | Reaming | |
| Group 1 | A CD | 300 350 | 160 175 | 160 175 | |
| Group 2 | A CD | 200 250 | 120 140 | 110 120 | |
| Group 3 | A CD | 100 110 | 60 65 | 50 60 | |

Abbreviations designate: A, annealed; CD, cold drawn.

Table 9. Cutting-Speed Adjustment Factors for Turning with HSS Tools

| Feed | | Feed Factor <i>F_f</i> | Depth of Cut | | Depth-of-Cut Factor <i>F_d</i> |
|-------|------|-------------------------------------|--------------|-------|--|
| in. | mm | | in. | mm | |
| 0.002 | 0.05 | 1.50 | 0.005 | 0.13 | 1.50 |
| 0.003 | 0.08 | 1.50 | 0.010 | 0.25 | 1.42 |
| 0.004 | 0.10 | 1.50 | 0.016 | 0.41 | 1.33 |
| 0.005 | 0.13 | 1.44 | 0.031 | 0.79 | 1.21 |
| 0.006 | 0.15 | 1.34 | 0.047 | 1.19 | 1.15 |
| 0.007 | 0.18 | 1.25 | 0.062 | 1.57 | 1.10 |
| 0.008 | 0.20 | 1.18 | 0.078 | 1.98 | 1.07 |
| 0.009 | 0.23 | 1.12 | 0.094 | 2.39 | 1.04 |
| 0.010 | 0.25 | 1.08 | 0.100 | 2.54 | 1.03 |
| 0.011 | 0.28 | 1.04 | 0.125 | 3.18 | 1.00 |
| 0.012 | 0.30 | 1.00 | 0.150 | 3.81 | 0.97 |
| 0.013 | 0.33 | 0.97 | 0.188 | 4.78 | 0.94 |
| 0.014 | 0.36 | 0.94 | 0.200 | 5.08 | 0.93 |
| 0.015 | 0.38 | 0.91 | 0.250 | 6.35 | 0.91 |
| 0.016 | 0.41 | 0.88 | 0.312 | 7.92 | 0.88 |
| 0.018 | 0.46 | 0.84 | 0.375 | 9.53 | 0.86 |
| 0.020 | 0.51 | 0.80 | 0.438 | 11.13 | 0.84 |
| 0.022 | 0.56 | 0.77 | 0.500 | 12.70 | 0.82 |
| 0.025 | 0.64 | 0.73 | 0.625 | 15.88 | 0.80 |
| 0.028 | 0.71 | 0.70 | 0.688 | 17.48 | 0.78 |
| 0.030 | 0.76 | 0.68 | 0.750 | 19.05 | 0.77 |
| 0.032 | 0.81 | 0.66 | 0.812 | 20.62 | 0.76 |
| 0.035 | 0.89 | 0.64 | 0.938 | 23.83 | 0.75 |
| 0.040 | 1.02 | 0.60 | 1.000 | 25.40 | 0.74 |
| 0.045 | 1.14 | 0.57 | 1.250 | 31.75 | 0.73 |
| 0.050 | 1.27 | 0.55 | 1.250 | 31.75 | 0.72 |
| 0.060 | 1.52 | 0.50 | 1.375 | 34.93 | 0.71 |

For use with HSS tool data only from Tables 1 through 8. Adjusted cutting speed $V = V_{HSS} \times F_f \times F_d$, where V_{HSS} is the tabular speed for turning with high-speed tools.

Table 10. Recommended Feed in Inches per Tooth (f_t) for Milling with High Speed Steel Cutters

| Material | Hardness, HB | End Mills | | | | | | | Plain or Slab Mills | Form Relieved Cutters | Face Mills and Shell End Mills | Slotting and Side Mills | | | | |
|---|-----------------|----------------------|---------------|----------|----------------------|---------------|---------------|----------|------------------------------|-----------------------------|---|----------------------------------|-----------|--|--|--|
| | | Depth of Cut,.250 in | | | Depth of Cut,.050 in | | | | | | | | | | | |
| | | Cutter Diam., in | | | Cutter Diam., in | | | | | | | | | | | |
| | | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 and up | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 and up | | | | | | | | |
| Feed per Tooth, inch | | | | | | | | | | | | | | | | |
| Free-machining plain carbon steels | 100–185 | .001 | .003 | .004 | .001 | .002 | .003 | .004 | .003–.008 | .005 | .004–.012 | .002–.008 | | | | |
| Plain carbon steels, AISI 1006 to 1030; 1513 to 1522 | 100–150 | .001 | .003 | .003 | .001 | .002 | .003 | .004 | .003–.008 | .004 | .004–.012 | .002–.008 | | | | |
| | 150–200 | .001 | .002 | .003 | .001 | .002 | .002 | .003 | .003–.008 | .004 | .003–.012 | .002–.008 | | | | |
| AISI 1033 to 1095; 1524 to 1566 | 120–180 | .001 | .003 | .003 | .001 | .002 | .003 | .004 | .003–.008 | .004 | .004–.012 | .002–.008 | | | | |
| | 180–220 | .001 | .002 | .003 | .001 | .002 | .002 | .003 | .003–.008 | .004 | .003–.012 | .002–.008 | | | | |
| | 220–300 | .001 | .002 | .002 | .001 | .001 | .002 | .003 | .002–.006 | .003 | .002–.008 | .002–.006 | | | | |
| Alloy steels having less than 3% carbon. Typical examples: AISI 4012, 4023, 4027, 4118, 4320 4422, 4427, 4615, 4620, 4626, 4720, 4820, 5015, 5120, 6118, 8115, 8620 8627, 8720, 8820, 8822, 9310, 93B17 | | 125–175 | .001 | .003 | .003 | .001 | .002 | .003 | .004 | .003–.008 | .004 | .004–.012 | .002–.008 | | | |
| | 175–225 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .003–.008 | .004 | .003–.012 | .002–.008 | | | | |
| | 225–275 | .001 | .002 | .003 | .001 | .001 | .002 | .003 | .002–.006 | .003 | .003–.008 | .002–.006 | | | | |
| | 275–325 | .001 | .002 | .002 | .001 | .001 | .002 | .002 | .002–.005 | .003 | .002–.008 | .002–.005 | | | | |
| Alloy steels having 3% carbon or more. Typical examples: AISI 1330, 1340, 4032, 4037, 4130, 4140, 4150, 4340, 50B40, 50B60, 5130, 51B60, 6150, 81B45, 8630, 8640, 86B45, 8660, 8740, 94B30 | | 175–225 | .001 | .002 | .003 | .001 | .002 | .003 | .004 | .003–.008 | .004 | .003–.012 | .002–.008 | | | |
| | 225–275 | .001 | .002 | .003 | .001 | .001 | .002 | .003 | .002–.006 | .003 | .003–.010 | .002–.006 | | | | |
| | 275–325 | .001 | .002 | .002 | .001 | .001 | .002 | .003 | .002–.005 | .003 | .002–.008 | .002–.005 | | | | |
| Tool steel | 325–375 | .001 | .002 | .002 | .001 | .001 | .002 | .002 | .002–.004 | .002 | .002–.008 | .002–.005 | | | | |
| | 150–200 | .001 | .002 | .002 | .001 | .002 | .003 | .003 | .003–.008 | .004 | .003–.010 | .002–.006 | | | | |
| Gray cast iron | 200–250 | .001 | .002 | .002 | .001 | .002 | .002 | .003 | .002–.006 | .003 | .003–.008 | .002–.005 | | | | |
| | 120–180 | .001 | .003 | .004 | .002 | .003 | .004 | .004 | .004–.012 | .005 | .005–.016 | .002–.010 | | | | |
| | 180–225 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .003–.010 | .004 | .004–.012 | .002–.008 | | | | |
| | 225–300 | .001 | .002 | .002 | .001 | .001 | .002 | .002 | .002–.006 | .003 | .002–.008 | .002–.005 | | | | |
| Free malleable iron | 110–160 | .001 | .003 | .004 | .002 | .003 | .004 | .004 | .003–.010 | .005 | .005–.016 | .002–.010 | | | | |

Table 10. Recommended Feed in Inches per Tooth (f_t) for Milling with High Speed Steel Cutters

| Material | Hardness, HB | End Mills | | | | | | | Plain or Slab Mills | Form Relieved Cutters | Face Mills and Shell End Mills | Slotting and Side Mills | | | | |
|--------------------------------------|-----------------|----------------------|---------------|----------|----------------------|---------------|---------------|----------|------------------------------|-----------------------------|---|----------------------------------|--|--|--|--|
| | | Depth of Cut,.250 in | | | Depth of Cut,.050 in | | | | | | | | | | | |
| | | Cutter Diam., in | | | Cutter Diam., in | | | | | | | | | | | |
| | | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 and up | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 and up | | | | | | | | |
| Feed per Tooth, inch | | | | | | | | | | | | | | | | |
| Pearlitic-Martensitic malleable iron | 160–200 | .001 | .003 | .004 | .001 | .002 | .003 | .004 | .003–.010 | .004 | .004–.012 | .002–.018 | | | | |
| | 200–240 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .003–.007 | .004 | .003–.010 | .002–.006 | | | | |
| | 240–300 | .001 | .002 | .002 | .001 | .001 | .002 | .002 | .002–.006 | .003 | .002–.008 | .002–.005 | | | | |
| Cast steel | 100–180 | .001 | .003 | .003 | .001 | .002 | .003 | .004 | .003–.008 | .004 | .003–.012 | .002–.008 | | | | |
| | 180–240 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .003–.008 | .004 | .003–.010 | .002–.006 | | | | |
| | 240–300 | .001 | .002 | .002 | .005 | .002 | .002 | .002 | .002–.006 | .003 | .003–.008 | .002–.005 | | | | |
| Zinc alloys (die castings) | ... | .002 | .003 | .004 | .001 | .003 | .004 | .006 | .003–.010 | .005 | .004–.015 | .002–.012 | | | | |
| Copper alloys (brasses & bronzes) | 100–150 | .002 | .004 | .005 | .002 | .003 | .005 | .006 | .003–.015 | .004 | .004–.020 | .002–.010 | | | | |
| | 150–250 | .002 | .003 | .004 | .001 | .003 | .004 | .005 | .003–.015 | .004 | .003–.012 | .002–.008 | | | | |
| Free cutting brasses & bronzes | 80–100 | .002 | .004 | .005 | .002 | .003 | .005 | .006 | .003–.015 | .004 | .004–.015 | .002–.010 | | | | |
| Cast aluminum alloys—as cast | ... | .003 | .004 | .005 | .002 | .004 | .005 | .006 | .005–.016 | .006 | .005–.020 | .004–.012 | | | | |
| Cast aluminum alloys—hardened | ... | .003 | .004 | .005 | .002 | .003 | .004 | .005 | .004–.012 | .005 | .005–.020 | .004–.012 | | | | |
| Wrought aluminum alloys— cold drawn | ... | .003 | .004 | .005 | .002 | .003 | .004 | .005 | .004–.014 | .005 | .005–.020 | .004–.012 | | | | |
| Wrought aluminum alloys—hardened | ... | .002 | .003 | .004 | .001 | .002 | .003 | .004 | .003–.012 | .004 | .005–.020 | .004–.012 | | | | |
| Magnesium alloys | ... | .003 | .004 | .005 | .003 | .004 | .005 | .007 | .005–.016 | .006 | .008–.020 | .005–.012 | | | | |
| Ferritic stainless steel | 135–185 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .002–.006 | .004 | .004–.008 | .002–.007 | | | | |
| Austenitic stainless steel | 135–185 | .001 | .002 | .003 | .001 | .002 | .003 | .003 | .003–.007 | .004 | .005–.008 | .002–.007 | | | | |
| | 185–275 | .001 | .002 | .003 | .001 | .002 | .002 | .002 | .003–.006 | .003 | .004–.006 | .002–.007 | | | | |
| Martensitic stainless steel | 135–185 | .001 | .002 | .002 | .001 | .002 | .003 | .003 | .003–.006 | .004 | .004–.010 | .002–.007 | | | | |
| | 185–225 | .001 | .002 | .002 | .001 | .002 | .002 | .003 | .003–.006 | .004 | .003–.008 | .002–.007 | | | | |
| | 225–300 | .0005 | .002 | .002 | .0005 | .001 | .002 | .002 | .002–.005 | .003 | .002–.006 | .002–.005 | | | | |
| Monel | 100–160 | .001 | .003 | .004 | .001 | .002 | .003 | .004 | .002–.006 | .004 | .002–.008 | .002–.006 | | | | |

Table 11. Cutting Speeds and Equivalent RPM for Drills of Number and Letter Sizes

| Size No. | Cutting Speed, Feet per Minute | | | | | | | | | | |
|----------|---|------|------|------|------|------|------|------|------|------|-------|
| | 30' | 40' | 50' | 60' | 70' | 80' | 90' | 100' | 110' | 130' | 150' |
| | Revolutions per Minute for Number Sizes | | | | | | | | | | |
| 1 | 503 | 670 | 838 | 1005 | 1173 | 1340 | 1508 | 1675 | 1843 | 2179 | 2513 |
| 2 | 518 | 691 | 864 | 1037 | 1210 | 1382 | 1555 | 1728 | 1901 | 2247 | 2593 |
| 4 | 548 | 731 | 914 | 1097 | 1280 | 1462 | 1645 | 1828 | 2010 | 2376 | 2741 |
| 6 | 562 | 749 | 936 | 1123 | 1310 | 1498 | 1685 | 1872 | 2060 | 2434 | 2809 |
| 8 | 576 | 768 | 960 | 1151 | 1343 | 1535 | 1727 | 1919 | 2111 | 2495 | 2879 |
| 10 | 592 | 790 | 987 | 1184 | 1382 | 1579 | 1777 | 1974 | 2171 | 2566 | 2961 |
| 12 | 606 | 808 | 1010 | 1213 | 1415 | 1617 | 1819 | 2021 | 2223 | 2627 | 3032 |
| 14 | 630 | 840 | 1050 | 1259 | 1469 | 1679 | 1889 | 2099 | 2309 | 2728 | 3148 |
| 16 | 647 | 863 | 1079 | 1295 | 1511 | 1726 | 1942 | 2158 | 2374 | 2806 | 3237 |
| 18 | 678 | 904 | 1130 | 1356 | 1582 | 1808 | 2034 | 2260 | 2479 | 2930 | 3380 |
| 20 | 712 | 949 | 1186 | 1423 | 1660 | 1898 | 2135 | 2372 | 2610 | 3084 | 3559 |
| 22 | 730 | 973 | 1217 | 1460 | 1703 | 1946 | 2190 | 2433 | 2676 | 3164 | 3649 |
| 24 | 754 | 1005 | 1257 | 1508 | 1759 | 2010 | 2262 | 2513 | 2764 | 3267 | 3769 |
| 26 | 779 | 1039 | 1299 | 1559 | 1819 | 2078 | 2338 | 2598 | 2858 | 3378 | 3898 |
| 28 | 816 | 1088 | 1360 | 1631 | 1903 | 2175 | 2447 | 2719 | 2990 | 3534 | 4078 |
| 30 | 892 | 1189 | 1487 | 1784 | 2081 | 2378 | 2676 | 2973 | 3270 | 3864 | 4459 |
| 32 | 988 | 1317 | 1647 | 1976 | 2305 | 2634 | 2964 | 3293 | 3622 | 4281 | 4939 |
| 34 | 1032 | 1376 | 1721 | 2065 | 2409 | 2753 | 3097 | 3442 | 3785 | 4474 | 5162 |
| 36 | 1076 | 1435 | 1794 | 2152 | 2511 | 2870 | 3228 | 3587 | 3945 | 4663 | 5380 |
| 38 | 1129 | 1505 | 1882 | 2258 | 2634 | 3010 | 3387 | 3763 | 4140 | 4892 | 5645 |
| 40 | 1169 | 1559 | 1949 | 2339 | 2729 | 3118 | 3508 | 3898 | 4287 | 5067 | 5846 |
| 42 | 1226 | 1634 | 2043 | 2451 | 2860 | 3268 | 3677 | 4085 | 4494 | 5311 | 6128 |
| 44 | 1333 | 1777 | 2221 | 2665 | 3109 | 3554 | 3999 | 4442 | 4886 | 5774 | 6662 |
| 46 | 1415 | 1886 | 2358 | 2830 | 3301 | 3773 | 4244 | 4716 | 5187 | 6130 | 7074 |
| 48 | 1508 | 2010 | 2513 | 3016 | 3518 | 4021 | 4523 | 5026 | 5528 | 6534 | 7539 |
| 50 | 1637 | 2183 | 2729 | 3274 | 3820 | 4366 | 4911 | 5457 | 6002 | 7094 | 8185 |
| 52 | 1805 | 2406 | 3008 | 3609 | 4211 | 4812 | 5414 | 6015 | 6619 | 7820 | 9023 |
| 54 | 2084 | 2778 | 3473 | 4167 | 4862 | 5556 | 6251 | 6945 | 7639 | 9028 | 10417 |
| Size | Revolutions per Minute for Letter Sizes | | | | | | | | | | |
| A | 491 | 654 | 818 | 982 | 1145 | 1309 | 1472 | 1636 | 1796 | 2122 | 2448 |
| B | 482 | 642 | 803 | 963 | 1124 | 1284 | 1445 | 1605 | 1765 | 2086 | 2407 |
| C | 473 | 631 | 789 | 947 | 1105 | 1262 | 1420 | 1578 | 1736 | 2052 | 2368 |
| D | 467 | 622 | 778 | 934 | 1089 | 1245 | 1400 | 1556 | 1708 | 2018 | 2329 |
| E | 458 | 611 | 764 | 917 | 1070 | 1222 | 1375 | 1528 | 1681 | 1968 | 2292 |
| F | 446 | 594 | 743 | 892 | 1040 | 1189 | 1337 | 1486 | 1635 | 1932 | 2229 |
| G | 440 | 585 | 732 | 878 | 1024 | 1170 | 1317 | 1463 | 1610 | 1903 | 2195 |
| H | 430 | 574 | 718 | 862 | 1005 | 1149 | 1292 | 1436 | 1580 | 1867 | 2154 |
| I | 421 | 562 | 702 | 842 | 983 | 1123 | 1264 | 1404 | 1545 | 1826 | 2106 |
| J | 414 | 552 | 690 | 827 | 965 | 1103 | 1241 | 1379 | 1517 | 1793 | 2068 |
| K | 408 | 544 | 680 | 815 | 951 | 1087 | 1223 | 1359 | 1495 | 1767 | 2039 |
| L | 395 | 527 | 659 | 790 | 922 | 1054 | 1185 | 1317 | 1449 | 1712 | 1976 |
| M | 389 | 518 | 648 | 777 | 907 | 1036 | 1166 | 1295 | 1424 | 1683 | 1942 |
| N | 380 | 506 | 633 | 759 | 886 | 1012 | 1139 | 1265 | 1391 | 1644 | 1897 |
| O | 363 | 484 | 605 | 725 | 846 | 967 | 1088 | 1209 | 1330 | 1571 | 1813 |
| P | 355 | 473 | 592 | 710 | 828 | 946 | 1065 | 1183 | 1301 | 1537 | 1774 |
| Q | 345 | 460 | 575 | 690 | 805 | 920 | 1035 | 1150 | 1266 | 1496 | 1726 |
| R | 338 | 451 | 564 | 676 | 789 | 902 | 1014 | 1127 | 1239 | 1465 | 1690 |
| S | 329 | 439 | 549 | 659 | 769 | 878 | 988 | 1098 | 1207 | 1427 | 1646 |
| T | 320 | 426 | 533 | 640 | 746 | 853 | 959 | 1066 | 1173 | 1387 | 1600 |
| U | 311 | 415 | 519 | 623 | 727 | 830 | 934 | 1038 | 1142 | 1349 | 1557 |
| V | 304 | 405 | 507 | 608 | 709 | 810 | 912 | 1013 | 1114 | 1317 | 1520 |
| W | 297 | 396 | 495 | 594 | 693 | 792 | 891 | 989 | 1088 | 1286 | 1484 |
| X | 289 | 385 | 481 | 576 | 672 | 769 | 865 | 962 | 1058 | 1251 | 1443 |
| Y | 284 | 378 | 473 | 567 | 662 | 756 | 851 | 945 | 1040 | 1229 | 1418 |
| Z | 277 | 370 | 462 | 555 | 647 | 740 | 832 | 925 | 1017 | 1202 | 1387 |

For fractional drill sizes, use Tables 12a and 12b.

Table 12a. Revolutions per Minute for Various Cutting Speeds and Diameters

| Diameter, Inches | Cutting Speed, Feet per Minute | | | | | | | | | | | |
|------------------------|--------------------------------|------|------|------|------|------|------|------|------|------|------|------|
| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 |
| Revolutions per Minute | | | | | | | | | | | | |
| 1/4 | 611 | 764 | 917 | 1070 | 1222 | 1376 | 1528 | 1834 | 2139 | 2445 | 2750 | 3056 |
| 5/16 | 489 | 611 | 733 | 856 | 978 | 1100 | 1222 | 1466 | 1711 | 1955 | 2200 | 2444 |
| 3/8 | 408 | 509 | 611 | 713 | 815 | 916 | 1018 | 1222 | 1425 | 1629 | 1832 | 2036 |
| 7/16 | 349 | 437 | 524 | 611 | 699 | 786 | 874 | 1049 | 1224 | 1398 | 1573 | 1748 |
| 1/2 | 306 | 382 | 459 | 535 | 611 | 688 | 764 | 917 | 1070 | 1222 | 1375 | 1528 |
| 9/16 | 272 | 340 | 407 | 475 | 543 | 611 | 679 | 813 | 951 | 1086 | 1222 | 1358 |
| 5/8 | 245 | 306 | 367 | 428 | 489 | 552 | 612 | 736 | 857 | 979 | 1102 | 1224 |
| 11/16 | 222 | 273 | 333 | 389 | 444 | 500 | 555 | 666 | 770 | 888 | 999 | 1101 |
| 3/4 | 203 | 254 | 306 | 357 | 408 | 458 | 508 | 610 | 711 | 813 | 914 | 1016 |
| 13/16 | 190 | 237 | 284 | 332 | 379 | 427 | 474 | 569 | 664 | 758 | 853 | 948 |
| 7/8 | 175 | 219 | 262 | 306 | 349 | 392 | 438 | 526 | 613 | 701 | 788 | 876 |
| 15/16 | 163 | 204 | 244 | 285 | 326 | 366 | 407 | 488 | 570 | 651 | 733 | 814 |
| 1 | 153 | 191 | 229 | 267 | 306 | 344 | 382 | 458 | 535 | 611 | 688 | 764 |
| 1 1/16 | 144 | 180 | 215 | 251 | 287 | 323 | 359 | 431 | 503 | 575 | 646 | 718 |
| 1 1/8 | 136 | 170 | 204 | 238 | 272 | 306 | 340 | 408 | 476 | 544 | 612 | 680 |
| 1 3/16 | 129 | 161 | 193 | 225 | 258 | 290 | 322 | 386 | 451 | 515 | 580 | 644 |
| 1 1/4 | 123 | 153 | 183 | 214 | 245 | 274 | 306 | 367 | 428 | 490 | 551 | 612 |
| 1 5/16 | 116 | 146 | 175 | 204 | 233 | 262 | 291 | 349 | 407 | 466 | 524 | 582 |
| 1 3/8 | 111 | 139 | 167 | 195 | 222 | 250 | 278 | 334 | 389 | 445 | 500 | 556 |
| 1 7/16 | 106 | 133 | 159 | 186 | 212 | 239 | 265 | 318 | 371 | 424 | 477 | 530 |
| 1 1/2 | 102 | 127 | 153 | 178 | 204 | 230 | 254 | 305 | 356 | 406 | 457 | 508 |
| 1 7/16 | 97.6 | 122 | 146 | 171 | 195 | 220 | 244 | 293 | 342 | 390 | 439 | 488 |
| 1 5/8 | 93.9 | 117 | 141 | 165 | 188 | 212 | 234 | 281 | 328 | 374 | 421 | 468 |
| 1 11/16 | 90.4 | 113 | 136 | 158 | 181 | 203 | 226 | 271 | 316 | 362 | 407 | 452 |
| 1 3/4 | 87.3 | 109 | 131 | 153 | 175 | 196 | 218 | 262 | 305 | 349 | 392 | 436 |
| 1 15/16 | 84.3 | 105 | 126 | 148 | 169 | 190 | 211 | 253 | 295 | 337 | 379 | 422 |
| 1 7/8 | 81.5 | 102 | 122 | 143 | 163 | 184 | 204 | 244 | 286 | 326 | 367 | 408 |
| 1 15/16 | 78.9 | 98 | 118 | 138 | 158 | 177 | 197 | 237 | 276 | 315 | 355 | 394 |
| 2 | 76.4 | 95.5 | 115 | 134 | 153 | 172 | 191 | 229 | 267 | 306 | 344 | 382 |
| 2 1/8 | 72.0 | 90.0 | 108 | 126 | 144 | 162 | 180 | 216 | 252 | 288 | 324 | 360 |
| 2 1/4 | 68.0 | 85.5 | 102 | 119 | 136 | 153 | 170 | 204 | 238 | 272 | 306 | 340 |
| 2 5/16 | 64.4 | 80.5 | 96.6 | 113 | 129 | 145 | 161 | 193 | 225 | 258 | 290 | 322 |
| 2 1/2 | 61.2 | 76.3 | 91.7 | 107 | 122 | 138 | 153 | 184 | 213 | 245 | 275 | 306 |
| 2 5/8 | 58.0 | 72.5 | 87.0 | 102 | 116 | 131 | 145 | 174 | 203 | 232 | 261 | 290 |
| 2 3/4 | 55.6 | 69.5 | 83.4 | 97.2 | 111 | 125 | 139 | 167 | 195 | 222 | 250 | 278 |
| 2 7/8 | 52.8 | 66.0 | 79.2 | 92.4 | 106 | 119 | 132 | 158 | 185 | 211 | 238 | 264 |
| 3 | 51.0 | 63.7 | 76.4 | 89.1 | 102 | 114 | 127 | 152 | 178 | 203 | 228 | 254 |
| 3 1/8 | 48.8 | 61.0 | 73.2 | 85.4 | 97.6 | 110 | 122 | 146 | 171 | 195 | 219 | 244 |
| 3 1/4 | 46.8 | 58.5 | 70.2 | 81.9 | 93.6 | 105 | 117 | 140 | 164 | 188 | 211 | 234 |
| 3 3/8 | 45.2 | 56.5 | 67.8 | 79.1 | 90.4 | 102 | 113 | 136 | 158 | 181 | 203 | 226 |
| 3 1/2 | 43.6 | 54.5 | 65.5 | 76.4 | 87.4 | 98.1 | 109 | 131 | 153 | 174 | 196 | 218 |
| 3 5/8 | 42.0 | 52.5 | 63.0 | 73.5 | 84.0 | 94.5 | 105 | 126 | 147 | 168 | 189 | 210 |
| 3 3/4 | 40.8 | 51.0 | 61.2 | 71.4 | 81.6 | 91.8 | 102 | 122 | 143 | 163 | 184 | 205 |
| 3 7/8 | 39.4 | 49.3 | 59.1 | 69.0 | 78.8 | 88.6 | 98.5 | 118 | 138 | 158 | 177 | 197 |
| 4 | 38.2 | 47.8 | 57.3 | 66.9 | 76.4 | 86.0 | 95.6 | 115 | 134 | 153 | 172 | 191 |
| 4 1/4 | 35.9 | 44.9 | 53.9 | 62.9 | 71.8 | 80.8 | 89.8 | 108 | 126 | 144 | 162 | 180 |
| 4 1/2 | 34.0 | 42.4 | 51.0 | 59.4 | 67.9 | 76.3 | 84.8 | 102 | 119 | 136 | 153 | 170 |
| 4 3/4 | 32.2 | 40.2 | 48.2 | 56.3 | 64.3 | 72.4 | 80.4 | 96.9 | 113 | 129 | 145 | 161 |
| 5 | 30.6 | 38.2 | 45.9 | 53.5 | 61.1 | 68.8 | 76.4 | 91.7 | 107 | 122 | 138 | 153 |
| 5 1/4 | 29.1 | 36.4 | 43.6 | 50.9 | 58.2 | 65.4 | 72.7 | 87.2 | 102 | 116 | 131 | 145 |
| 5 1/2 | 27.8 | 34.7 | 41.7 | 48.6 | 55.6 | 62.5 | 69.4 | 83.3 | 97.2 | 111 | 125 | 139 |
| 5 3/4 | 26.6 | 33.2 | 39.8 | 46.5 | 53.1 | 59.8 | 66.4 | 80.0 | 93.0 | 106 | 120 | 133 |
| 6 | 25.5 | 31.8 | 38.2 | 44.6 | 51.0 | 57.2 | 63.6 | 76.3 | 89.0 | 102 | 114 | 127 |
| 6 1/4 | 24.4 | 30.6 | 36.7 | 42.8 | 48.9 | 55.0 | 61.1 | 73.3 | 85.5 | 97.7 | 110 | 122 |
| 6 1/2 | 23.5 | 29.4 | 35.2 | 41.1 | 47.0 | 52.8 | 58.7 | 70.4 | 82.2 | 93.9 | 106 | 117 |
| 6 3/4 | 22.6 | 28.3 | 34.0 | 39.6 | 45.3 | 50.9 | 56.6 | 67.9 | 79.2 | 90.6 | 102 | 113 |
| 7 | 21.8 | 27.3 | 32.7 | 38.2 | 43.7 | 49.1 | 54.6 | 65.5 | 76.4 | 87.4 | 98.3 | 109 |
| 7 1/4 | 21.1 | 26.4 | 31.6 | 36.9 | 42.2 | 47.4 | 52.7 | 63.2 | 73.8 | 84.3 | 94.9 | 105 |
| 7 1/2 | 20.4 | 25.4 | 30.5 | 35.6 | 40.7 | 45.8 | 50.9 | 61.1 | 71.0 | 81.4 | 91.6 | 102 |
| 7 3/4 | 19.7 | 24.6 | 29.5 | 34.4 | 39.4 | 44.3 | 49.2 | 59.0 | 68.9 | 78.7 | 88.6 | 98.4 |
| 8 | 19.1 | 23.9 | 28.7 | 33.4 | 38.2 | 43.0 | 47.8 | 57.4 | 66.9 | 76.5 | 86.0 | 95.6 |

Table 12b. Revolutions per Minute for Various Cutting Speeds and Diameters

| Diameter, Inches | Cutting Speed, Feet per Minute | | | | | | | | | | | |
|------------------------|--------------------------------|------|------|------|------|------|------|------|------|------|------|------|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 500 | 550 |
| Revolutions per Minute | | | | | | | | | | | | |
| 1/4 | 3438 | 3820 | 4202 | 4584 | 4966 | 5348 | 5730 | 6112 | 6493 | 6875 | 7639 | 8403 |
| 5/16 | 2750 | 3056 | 3362 | 3667 | 3973 | 4278 | 4584 | 4889 | 5195 | 5501 | 6112 | 6723 |
| 3/8 | 2292 | 2546 | 2801 | 3056 | 3310 | 3565 | 3820 | 4074 | 4329 | 4584 | 5093 | 5602 |
| 7/16 | 1964 | 2182 | 2401 | 2619 | 2837 | 3056 | 3274 | 3492 | 3710 | 3929 | 4365 | 4802 |
| 1/2 | 1719 | 1910 | 2101 | 2292 | 2483 | 2675 | 2866 | 3057 | 3248 | 3439 | 3821 | 4203 |
| 9/16 | 1528 | 1698 | 1868 | 2037 | 2207 | 2377 | 2547 | 2717 | 2887 | 3056 | 3396 | 3736 |
| 5/8 | 1375 | 1528 | 1681 | 1834 | 1987 | 2139 | 2292 | 2445 | 2598 | 2751 | 3057 | 3362 |
| 11/16 | 1250 | 1389 | 1528 | 1667 | 1806 | 1941 | 2084 | 2223 | 2362 | 2501 | 2779 | 3056 |
| 3/4 | 1146 | 1273 | 1401 | 1528 | 1655 | 1783 | 1910 | 2038 | 2165 | 2292 | 2547 | 2802 |
| 13/16 | 1058 | 1175 | 1293 | 1410 | 1528 | 1646 | 1763 | 1881 | 1998 | 2116 | 2351 | 2586 |
| 7/8 | 982 | 1091 | 1200 | 1310 | 1419 | 1528 | 1637 | 1746 | 1855 | 1965 | 2183 | 2401 |
| 15/16 | 917 | 1019 | 1120 | 1222 | 1324 | 1426 | 1528 | 1630 | 1732 | 1834 | 2038 | 2241 |
| 1 | 859 | 955 | 1050 | 1146 | 1241 | 1337 | 1432 | 1528 | 1623 | 1719 | 1910 | 2101 |
| 1 1/16 | 809 | 899 | 988 | 1078 | 1168 | 1258 | 1348 | 1438 | 1528 | 1618 | 1798 | 1977 |
| 1 1/8 | 764 | 849 | 933 | 1018 | 1103 | 1188 | 1273 | 1358 | 1443 | 1528 | 1698 | 1867 |
| 1 3/16 | 724 | 804 | 884 | 965 | 1045 | 1126 | 1206 | 1287 | 1367 | 1448 | 1609 | 1769 |
| 1 1/4 | 687 | 764 | 840 | 917 | 993 | 1069 | 1146 | 1222 | 1299 | 1375 | 1528 | 1681 |
| 1 5/16 | 654 | 727 | 800 | 873 | 946 | 1018 | 1091 | 1164 | 1237 | 1309 | 1455 | 1601 |
| 1 3/8 | 625 | 694 | 764 | 833 | 903 | 972 | 1042 | 1111 | 1181 | 1250 | 1389 | 1528 |
| 1 7/16 | 598 | 664 | 730 | 797 | 863 | 930 | 996 | 1063 | 1129 | 1196 | 1329 | 1461 |
| 1 1/2 | 573 | 636 | 700 | 764 | 827 | 891 | 955 | 1018 | 1082 | 1146 | 1273 | 1400 |
| 1 9/16 | 550 | 611 | 672 | 733 | 794 | 855 | 916 | 978 | 1039 | 1100 | 1222 | 1344 |
| 1 5/8 | 528 | 587 | 646 | 705 | 764 | 822 | 881 | 940 | 999 | 1057 | 1175 | 1293 |
| 1 11/16 | 509 | 566 | 622 | 679 | 735 | 792 | 849 | 905 | 962 | 1018 | 1132 | 1245 |
| 1 3/4 | 491 | 545 | 600 | 654 | 709 | 764 | 818 | 873 | 927 | 982 | 1091 | 1200 |
| 1 13/16 | 474 | 527 | 579 | 632 | 685 | 737 | 790 | 843 | 895 | 948 | 1054 | 1159 |
| 1 7/8 | 458 | 509 | 560 | 611 | 662 | 713 | 764 | 815 | 866 | 917 | 1019 | 1120 |
| 1 15/16 | 443 | 493 | 542 | 591 | 640 | 690 | 739 | 788 | 838 | 887 | 986 | 1084 |
| 2 | 429 | 477 | 525 | 573 | 620 | 668 | 716 | 764 | 811 | 859 | 955 | 1050 |
| 2 1/8 | 404 | 449 | 494 | 539 | 584 | 629 | 674 | 719 | 764 | 809 | 899 | 988 |
| 2 1/4 | 382 | 424 | 468 | 509 | 551 | 594 | 636 | 679 | 721 | 764 | 849 | 933 |
| 2 3/8 | 362 | 402 | 442 | 482 | 522 | 563 | 603 | 643 | 683 | 724 | 804 | 884 |
| 2 1/2 | 343 | 382 | 420 | 458 | 496 | 534 | 573 | 611 | 649 | 687 | 764 | 840 |
| 2 5/8 | 327 | 363 | 400 | 436 | 472 | 509 | 545 | 582 | 618 | 654 | 727 | 800 |
| 2 3/4 | 312 | 347 | 381 | 416 | 451 | 486 | 520 | 555 | 590 | 625 | 694 | 763 |
| 2 7/8 | 299 | 332 | 365 | 398 | 431 | 465 | 498 | 531 | 564 | 598 | 664 | 730 |
| 3 | 286 | 318 | 350 | 381 | 413 | 445 | 477 | 509 | 541 | 572 | 636 | 700 |
| 3 1/8 | 274 | 305 | 336 | 366 | 397 | 427 | 458 | 488 | 519 | 549 | 611 | 672 |
| 3 1/4 | 264 | 293 | 323 | 352 | 381 | 411 | 440 | 470 | 499 | 528 | 587 | 646 |
| 3 3/8 | 254 | 283 | 311 | 339 | 367 | 396 | 424 | 452 | 481 | 509 | 566 | 622 |
| 3 1/2 | 245 | 272 | 300 | 327 | 354 | 381 | 409 | 436 | 463 | 490 | 545 | 600 |
| 3 5/8 | 237 | 263 | 289 | 316 | 342 | 368 | 395 | 421 | 447 | 474 | 527 | 579 |
| 3 3/4 | 229 | 254 | 280 | 305 | 331 | 356 | 382 | 407 | 433 | 458 | 509 | 560 |
| 3 7/8 | 221 | 246 | 271 | 295 | 320 | 345 | 369 | 394 | 419 | 443 | 493 | 542 |
| 4 | 214 | 238 | 262 | 286 | 310 | 334 | 358 | 382 | 405 | 429 | 477 | 525 |
| 4 1/4 | 202 | 224 | 247 | 269 | 292 | 314 | 337 | 359 | 383 | 404 | 449 | 494 |
| 4 1/2 | 191 | 212 | 233 | 254 | 275 | 297 | 318 | 339 | 360 | 382 | 424 | 466 |
| 4 3/4 | 180 | 201 | 221 | 241 | 261 | 281 | 301 | 321 | 341 | 361 | 402 | 442 |
| 5 | 171 | 191 | 210 | 229 | 248 | 267 | 286 | 305 | 324 | 343 | 382 | 420 |
| 5 1/4 | 163 | 181 | 199 | 218 | 236 | 254 | 272 | 290 | 308 | 327 | 363 | 399 |
| 5 1/2 | 156 | 173 | 190 | 208 | 225 | 242 | 260 | 277 | 294 | 312 | 347 | 381 |
| 5 3/4 | 149 | 166 | 182 | 199 | 215 | 232 | 249 | 265 | 282 | 298 | 332 | 365 |
| 6 | 143 | 159 | 174 | 190 | 206 | 222 | 238 | 254 | 270 | 286 | 318 | 349 |
| 6 1/4 | 137 | 152 | 168 | 183 | 198 | 213 | 229 | 244 | 259 | 274 | 305 | 336 |
| 6 1/2 | 132 | 146 | 161 | 176 | 190 | 205 | 220 | 234 | 249 | 264 | 293 | 322 |
| 6 3/4 | 127 | 141 | 155 | 169 | 183 | 198 | 212 | 226 | 240 | 254 | 283 | 311 |
| 7 | 122 | 136 | 149 | 163 | 177 | 190 | 204 | 218 | 231 | 245 | 272 | 299 |
| 7 1/4 | 118 | 131 | 144 | 158 | 171 | 184 | 197 | 210 | 223 | 237 | 263 | 289 |
| 7 1/2 | 114 | 127 | 139 | 152 | 165 | 178 | 190 | 203 | 216 | 229 | 254 | 279 |
| 7 3/4 | 111 | 123 | 135 | 148 | 160 | 172 | 185 | 197 | 209 | 222 | 246 | 271 |
| 8 | 107 | 119 | 131 | 143 | 155 | 167 | 179 | 191 | 203 | 215 | 238 | 262 |

**Table 13a. Revolutions per Minute for Various Cutting Speeds and Diameters
(Metric Units)**

| Diam., mm | Cutting Speed, Meters per Minute | | | | | | | | | | | |
|--------------|----------------------------------|------|------|------|------|------|------|------|------|------|------|------|
| | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 30 | 35 | 40 | 45 |
| | Revolutions per Minute | | | | | | | | | | | |
| 5 | 318 | 382 | 509 | 637 | 764 | 1019 | 1273 | 1592 | 1910 | 2228 | 2546 | 2865 |
| 6 | 265 | 318 | 424 | 530 | 637 | 849 | 1061 | 1326 | 1592 | 1857 | 2122 | 2387 |
| 8 | 199 | 239 | 318 | 398 | 477 | 637 | 796 | 995 | 1194 | 1393 | 1592 | 1790 |
| 10 | 159 | 191 | 255 | 318 | 382 | 509 | 637 | 796 | 955 | 1114 | 1273 | 1432 |
| 12 | 133 | 159 | 212 | 265 | 318 | 424 | 531 | 663 | 796 | 928 | 1061 | 1194 |
| 16 | 99.5 | 119 | 159 | 199 | 239 | 318 | 398 | 497 | 597 | 696 | 796 | 895 |
| 20 | 79.6 | 95.5 | 127 | 159 | 191 | 255 | 318 | 398 | 477 | 557 | 637 | 716 |
| 25 | 63.7 | 76.4 | 102 | 127 | 153 | 204 | 255 | 318 | 382 | 446 | 509 | 573 |
| 30 | 53.1 | 63.7 | 84.9 | 106 | 127 | 170 | 212 | 265 | 318 | 371 | 424 | 477 |
| 35 | 45.5 | 54.6 | 72.8 | 90.9 | 109 | 145 | 182 | 227 | 273 | 318 | 364 | 409 |
| 40 | 39.8 | 47.7 | 63.7 | 79.6 | 95.5 | 127 | 159 | 199 | 239 | 279 | 318 | 358 |
| 45 | 35.4 | 42.4 | 56.6 | 70.7 | 84.9 | 113 | 141 | 177 | 212 | 248 | 283 | 318 |
| 50 | 31.8 | 38.2 | 51 | 63.7 | 76.4 | 102 | 127 | 159 | 191 | 223 | 255 | 286 |
| 55 | 28.9 | 34.7 | 46.3 | 57.9 | 69.4 | 92.6 | 116 | 145 | 174 | 203 | 231 | 260 |
| 60 | 26.6 | 31.8 | 42.4 | 53.1 | 63.7 | 84.9 | 106 | 133 | 159 | 186 | 212 | 239 |
| 65 | 24.5 | 29.4 | 39.2 | 49 | 58.8 | 78.4 | 98 | 122 | 147 | 171 | 196 | 220 |
| 70 | 22.7 | 27.3 | 36.4 | 45.5 | 54.6 | 72.8 | 90.9 | 114 | 136 | 159 | 182 | 205 |
| 75 | 21.2 | 25.5 | 34 | 42.4 | 51 | 68 | 84.9 | 106 | 127 | 149 | 170 | 191 |
| 80 | 19.9 | 23.9 | 31.8 | 39.8 | 47.7 | 63.7 | 79.6 | 99.5 | 119 | 139 | 159 | 179 |
| 90 | 17.7 | 21.2 | 28.3 | 35.4 | 42.4 | 56.6 | 70.7 | 88.4 | 106 | 124 | 141 | 159 |
| 100 | 15.9 | 19.1 | 25.5 | 31.8 | 38.2 | 51 | 63.7 | 79.6 | 95.5 | 111 | 127 | 143 |
| 110 | 14.5 | 17.4 | 23.1 | 28.9 | 34.7 | 46.2 | 57.9 | 72.3 | 86.8 | 101 | 116 | 130 |
| 120 | 13.3 | 15.9 | 21.2 | 26.5 | 31.8 | 42.4 | 53.1 | 66.3 | 79.6 | 92.8 | 106 | 119 |
| 130 | 12.2 | 14.7 | 19.6 | 24.5 | 29.4 | 39.2 | 49 | 61.2 | 73.4 | 85.7 | 97.9 | 110 |
| 140 | 11.4 | 13.6 | 18.2 | 22.7 | 27.3 | 36.4 | 45.5 | 56.8 | 68.2 | 79.6 | 90.9 | 102 |
| 150 | 10.6 | 12.7 | 17 | 21.2 | 25.5 | 34 | 42.4 | 53.1 | 63.7 | 74.3 | 84.9 | 95.5 |
| 160 | 9.9 | 11.9 | 15.9 | 19.9 | 23.9 | 31.8 | 39.8 | 49.7 | 59.7 | 69.6 | 79.6 | 89.5 |
| 170 | 9.4 | 11.2 | 15 | 18.7 | 22.5 | 30 | 37.4 | 46.8 | 56.2 | 65.5 | 74.9 | 84.2 |
| 180 | 8.8 | 10.6 | 14.1 | 17.7 | 21.2 | 28.3 | 35.4 | 44.2 | 53.1 | 61.9 | 70.7 | 79.6 |
| 190 | 8.3 | 10 | 13.4 | 16.8 | 20.1 | 26.8 | 33.5 | 41.9 | 50.3 | 58.6 | 67 | 75.4 |
| 200 | 8 | 9.5 | 12.7 | 15.9 | 19.1 | 25.5 | 31.8 | 39.8 | 47.7 | 55.7 | 63.7 | 71.6 |
| 220 | 7.2 | 8.7 | 11.6 | 14.5 | 17.4 | 23.1 | 28.9 | 36.2 | 43.4 | 50.6 | 57.9 | 65.1 |
| 240 | 6.6 | 8 | 10.6 | 13.3 | 15.9 | 21.2 | 26.5 | 33.2 | 39.8 | 46.4 | 53.1 | 59.7 |
| 260 | 6.1 | 7.3 | 9.8 | 12.2 | 14.7 | 19.6 | 24.5 | 30.6 | 36.7 | 42.8 | 49 | 55.1 |
| 280 | 5.7 | 6.8 | 9.1 | 11.4 | 13.6 | 18.2 | 22.7 | 28.4 | 34.1 | 39.8 | 45.5 | 51.1 |
| 300 | 5.3 | 6.4 | 8.5 | 10.6 | 12.7 | 17 | 21.2 | 26.5 | 31.8 | 37.1 | 42.4 | 47.7 |
| 350 | 4.5 | 5.4 | 7.3 | 9.1 | 10.9 | 14.6 | 18.2 | 22.7 | 27.3 | 31.8 | 36.4 | 40.9 |
| 400 | 4 | 4.8 | 6.4 | 8 | 9.5 | 12.7 | 15.9 | 19.9 | 23.9 | 27.9 | 31.8 | 35.8 |
| 450 | 3.5 | 4.2 | 5.7 | 7.1 | 8.5 | 11.3 | 14.1 | 17.7 | 21.2 | 24.8 | 28.3 | 31.8 |
| 500 | 3.2 | 3.8 | 5.1 | 6.4 | 7.6 | 10.2 | 12.7 | 15.9 | 19.1 | 22.3 | 25.5 | 28.6 |

Table 13b. Revolutions per Minute for Various Cutting Speeds and Diameters (Metric Units)

| Diam. mm | Cutting Speed, Meters per Minute | | | | | | | | | | | |
|-------------|----------------------------------|------|------|------|------|------|------|------|------|------|------|--------|
| | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 200 |
| | Revolutions per Minute | | | | | | | | | | | |
| 5 | 3183 | 3501 | 3820 | 4138 | 4456 | 4775 | 5093 | 5411 | 5730 | 6048 | 6366 | 12,732 |
| 6 | 2653 | 2918 | 3183 | 3448 | 3714 | 3979 | 4244 | 4509 | 4775 | 5039 | 5305 | 10,610 |
| 8 | 1989 | 2188 | 2387 | 2586 | 2785 | 2984 | 3183 | 3382 | 3581 | 3780 | 3979 | 7958 |
| 10 | 1592 | 1751 | 1910 | 2069 | 2228 | 2387 | 2546 | 2706 | 2865 | 3024 | 3183 | 6366 |
| 12 | 1326 | 1459 | 1592 | 1724 | 1857 | 1989 | 2122 | 2255 | 2387 | 2520 | 2653 | 5305 |
| 16 | 995 | 1094 | 1194 | 1293 | 1393 | 1492 | 1591 | 1691 | 1790 | 1890 | 1989 | 3979 |
| 20 | 796 | 875 | 955 | 1034 | 1114 | 1194 | 1273 | 1353 | 1432 | 1512 | 1592 | 3183 |
| 25 | 637 | 700 | 764 | 828 | 891 | 955 | 1019 | 1082 | 1146 | 1210 | 1273 | 2546 |
| 30 | 530 | 584 | 637 | 690 | 743 | 796 | 849 | 902 | 955 | 1008 | 1061 | 2122 |
| 35 | 455 | 500 | 546 | 591 | 637 | 682 | 728 | 773 | 819 | 864 | 909 | 1818 |
| 40 | 398 | 438 | 477 | 517 | 557 | 597 | 637 | 676 | 716 | 756 | 796 | 1592 |
| 45 | 354 | 389 | 424 | 460 | 495 | 531 | 566 | 601 | 637 | 672 | 707 | 1415 |
| 50 | 318 | 350 | 382 | 414 | 446 | 477 | 509 | 541 | 573 | 605 | 637 | 1273 |
| 55 | 289 | 318 | 347 | 376 | 405 | 434 | 463 | 492 | 521 | 550 | 579 | 1157 |
| 60 | 265 | 292 | 318 | 345 | 371 | 398 | 424 | 451 | 477 | 504 | 530 | 1061 |
| 65 | 245 | 269 | 294 | 318 | 343 | 367 | 392 | 416 | 441 | 465 | 490 | 979 |
| 70 | 227 | 250 | 273 | 296 | 318 | 341 | 364 | 387 | 409 | 432 | 455 | 909 |
| 75 | 212 | 233 | 255 | 276 | 297 | 318 | 340 | 361 | 382 | 403 | 424 | 849 |
| 80 | 199 | 219 | 239 | 259 | 279 | 298 | 318 | 338 | 358 | 378 | 398 | 796 |
| 90 | 177 | 195 | 212 | 230 | 248 | 265 | 283 | 301 | 318 | 336 | 354 | 707 |
| 100 | 159 | 175 | 191 | 207 | 223 | 239 | 255 | 271 | 286 | 302 | 318 | 637 |
| 110 | 145 | 159 | 174 | 188 | 203 | 217 | 231 | 246 | 260 | 275 | 289 | 579 |
| 120 | 133 | 146 | 159 | 172 | 186 | 199 | 212 | 225 | 239 | 252 | 265 | 530 |
| 130 | 122 | 135 | 147 | 159 | 171 | 184 | 196 | 208 | 220 | 233 | 245 | 490 |
| 140 | 114 | 125 | 136 | 148 | 159 | 171 | 182 | 193 | 205 | 216 | 227 | 455 |
| 150 | 106 | 117 | 127 | 138 | 149 | 159 | 170 | 180 | 191 | 202 | 212 | 424 |
| 160 | 99.5 | 109 | 119 | 129 | 139 | 149 | 159 | 169 | 179 | 189 | 199 | 398 |
| 170 | 93.6 | 103 | 112 | 122 | 131 | 140 | 150 | 159 | 169 | 178 | 187 | 374 |
| 180 | 88.4 | 97.3 | 106 | 115 | 124 | 133 | 141 | 150 | 159 | 168 | 177 | 354 |
| 190 | 83.8 | 92.1 | 101 | 109 | 117 | 126 | 134 | 142 | 151 | 159 | 167 | 335 |
| 200 | 79.6 | 87.5 | 95.5 | 103 | 111 | 119 | 127 | 135 | 143 | 151 | 159 | 318 |
| 220 | 72.3 | 79.6 | 86.8 | 94 | 101 | 109 | 116 | 123 | 130 | 137 | 145 | 289 |
| 240 | 66.3 | 72.9 | 79.6 | 86.2 | 92.8 | 99.5 | 106 | 113 | 119 | 126 | 132 | 265 |
| 260 | 61.2 | 67.3 | 73.4 | 79.6 | 85.7 | 91.8 | 97.9 | 104 | 110 | 116 | 122 | 245 |
| 280 | 56.8 | 62.5 | 68.2 | 73.9 | 79.6 | 85.3 | 90.9 | 96.6 | 102 | 108 | 114 | 227 |
| 300 | 53.1 | 58.3 | 63.7 | 69 | 74.3 | 79.6 | 84.9 | 90.2 | 95.5 | 101 | 106 | 212 |
| 350 | 45.5 | 50 | 54.6 | 59.1 | 63.7 | 68.2 | 72.8 | 77.3 | 81.8 | 99.1 | 91 | 182 |
| 400 | 39.8 | 43.8 | 47.7 | 51.7 | 55.7 | 59.7 | 63.7 | 67.6 | 71.6 | 75.6 | 79.6 | 159 |
| 450 | 35.4 | 38.9 | 42.4 | 46 | 49.5 | 53.1 | 56.6 | 60.1 | 63.6 | 67.2 | 70.7 | 141 |
| 500 | 31.8 | 35 | 38.2 | 41.4 | 44.6 | 47.7 | 50.9 | 54.1 | 57.3 | 60.5 | 63.6 | 127 |

Speeds and Feeds in Diamond Grinding.—General recommendations are as follows:

Wheel Speeds: The generally recommended wheel speeds for diamond grinding are in the range of 5000 to 6000 surface feet per minute, with this upper limit as a maximum to avoid harmful "overspeeding." Exceptions from that general rule are diamond wheels with coarse grains and high concentration (100 per cent) where the wheel wear in dry surface grinding can be reduced by lowering the speed to 2500–3000 sfpm. However, this lower speed range can cause rapid wheel breakdown in finer grit wheels or in those with reduced diamond concentration.

Work Speeds: In diamond grinding, work rotation and table traverse are usually established by experience, adjusting these values to the selected infeed so as to avoid excessive wheel wear.

Infeed per Pass: Often referred to as downfeed and usually a function of the grit size of the wheel. The following are general values which may be increased for raising the productivity, or lowered to improve finish or to reduce wheel wear.

| Wheel Grit Size Range | Infeed per Pass |
|-----------------------|-----------------|
| 100 to 120 | 0.001 inch |
| 150 to 220 | 0.0005 inch |
| 250 and finer | 0.00025 inch |

Table 14. Speeds and Feeds for Drilling Holes of 0.25 to 0.375 in. Diameter in Various Thermoplastics

| Material | Speed (rpm) | Feed ^a | Comments |
|-------------------------|-------------|-------------------|------------------------------|
| Polyethylene | 1000–2000 | H | Easy to machine |
| Polyvinyl chloride | 1000–2000 | M | Tends to become gummy |
| Acrylic | 500–1500 | M–H | Easy to drill with lubricant |
| Polystyrene | 500–1500 | H | Must have coolant |
| ABS | 500–1000 | M–H | |
| Polytetrafluoroethylene | 1000 | L–M | Easy to drill |
| Nylon 6/6 | 1000 | H | Easy to drill |
| Polycarbonate | 500–1500 | M–H | Easy to drill, some gumming |
| Acetal | 1000–2000 | H | Easy to drill |
| Polypropylene | 1000–2000 | H | Easy to drill |
| Polyester | 1000–1500 | H | Easy to drill |

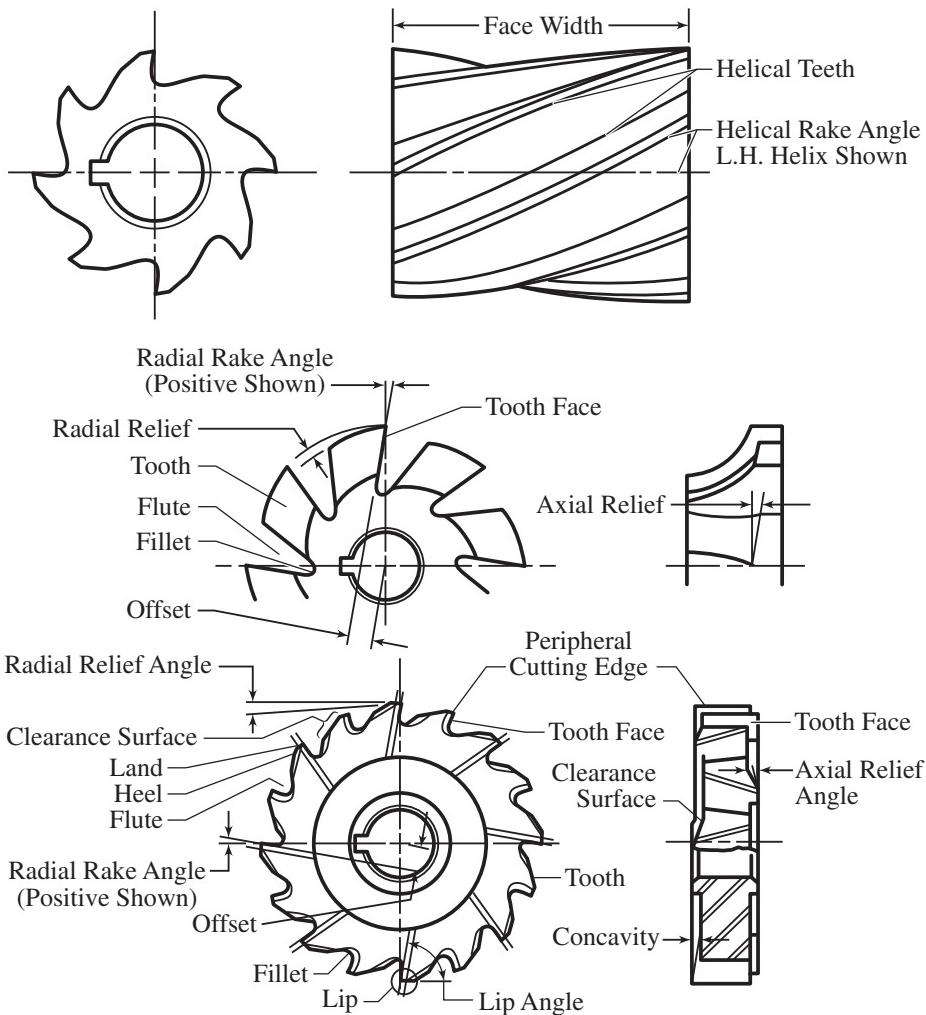
^aH = high; M = medium; L = low.

Table 15. Speeds and Numbers of Teeth for Sawing Plastics Materials with High-Carbon Steel Saw Blades

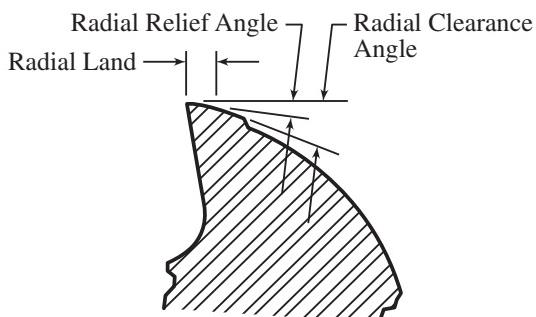
| Material Thickness (in.) | Number of Teeth on Blade | Peripheral Speed (ft/min) | |
|--------------------------|--------------------------|-----------------------------------|----------------|
| | | Thermoset Cast or Molded Plastics | Thermoplastics |
| 0–0.5 | 8–14 | 2000–3000 | 4000–5000 |
| 0.5–1 | 6–8 | 1800–2200 | 3500–4300 |
| 1–3 | 3 | 1500–2200 | 3000–3500 |
| >3 | >3 | 1200–1800 | 2500–3000 |

MILLING CUTTERS

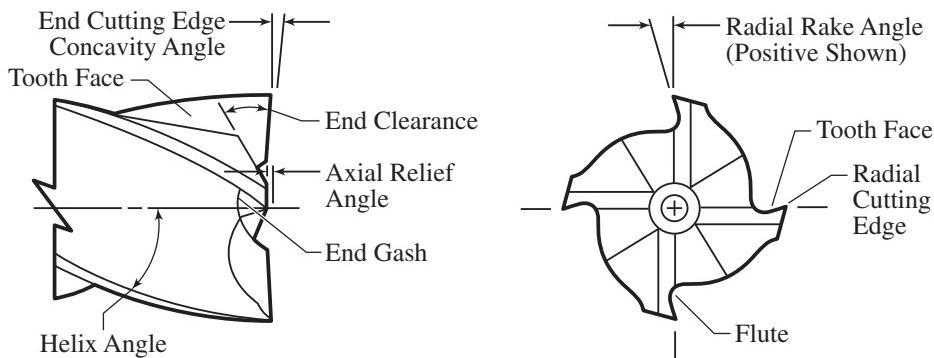
Milling Cutter Terms



End Mill Terms



Enlarged Section of End Mill Tooth

End Mill Terms (Continued)

Enlarged Section of End Mill

Wheels for Sharpening Milling Cutters.— Milling cutters may be sharpened either by using the periphery of a disk wheel or the face of a cup wheel. The latter grinds the lands of the teeth flat, whereas the periphery of a disk wheel leaves the teeth slightly concave back of the cutting edges. The concavity produced by disk wheels reduces the effective clearance angle on the teeth, the effect being more pronounced for wheels of small diameter than for wheels of large diameter. For this reason, large diameter wheels are preferred when sharpening milling cutters with disk type wheels. Irrespective of what type of wheel is used to sharpen a milling cutter, any burrs resulting from grinding should be carefully removed by a hand stoning operation. Stoning also helps to reduce the roughness of grinding marks and improves the quality of the finish produced on the surface being machined. Unless done very carefully, hand stoning may dull the cutting edge. Stoning may be avoided and a sharper cutting edge produced if the wheel rotates toward the cutting edge, which requires that the operator maintain contact between the tool and the rest while the wheel rotation is trying to move the tool away from the rest. Though slightly more difficult, this method will eliminate the burr.

Table 1. Specifications of Grinding Wheels for Sharpening Milling Cutters

| Cutter Material | Operation | Grinding Wheel | | | |
|---|--|--|------------------------|-----------------|-----------------------------------|
| | | Abrasives Material | Grain Size | Grade | Bond |
| Carbon Tool Steel | Roughing Finishing | Aluminum Oxide Aluminum Oxide | 46–60 100 | K H | Vitrified Vitrified |
| High-speed Steel: | | | | | |
| 18-4-1 { | Roughing Finishing | Aluminum Oxide Aluminum Oxide | 60 100 | K,H H | Vitrified Vitrified |
| 18-4-2 { | Roughing Finishing | Aluminum Oxide Aluminum Oxide | 80 100 | F,G,H H | Vitrified Vitrified |
| Cast Non-Ferrous Tool Material | Roughing Finishing | Aluminum Oxide Aluminum Oxide | 46 100–120 | H, K, L, N H | Vitrified Vitrified |
| Sintered Carbide | Roughing after Brazing Roughing Finishing | Silicon Carbide Diamond Diamond | 60 100 Up to 500 | G a a | Vitrified Resinoid Resinoid |
| Carbon Tool Steel and High-Speed Steel ^b | Roughing Finishing | Cubic Boron Nitride Cubic Boron Nitride | 80–100 100–120 | R, P S, T | Resinoid Resinoid |

^a Not indicated in diamond wheel markings.^b For hardnesses above Rockwell C 56.

Wheel Speeds and Feeds for Sharpening Milling Cutters.—Relatively low cutting speeds should be used when sharpening milling cutters to avoid tempering and heat checking. Dry grinding is recommended in all cases except when diamond wheels are employed. The surface speed of grinding wheels should be in the range of 4500 to 6500 feet per minute for grinding milling cutters of high-speed steel or cast non-ferrous tool material. For sintered carbide cutters, 5000 to 5500 feet per minute should be used.

The maximum stock removed per pass of the grinding wheel should not exceed about 0.0004 inch for sintered carbide cutters; 0.003 inch for large high-speed steel and cast non-ferrous tool material cutters; and 0.0015 inch for narrow saws and slotting cutters of high-speed steel or cast non-ferrous tool material. The stock removed per pass of the wheel may be increased for backing-off operations such as the grinding of secondary clearance behind the teeth since there is usually a sufficient body of metal to carry off the heat.

Clearance Angles for Milling Cutter Teeth.—The clearance angle provided on the cutting edges of milling cutters has an important bearing on cutter performance, cutting efficiency, and cutter life between sharpenings. It is desirable in all cases to use a clearance angle as small as possible so as to leave more metal back of the cutting edges for better heat dissipation and to provide maximum support. Excessive clearance angles not only weaken the cutting edges, but also increase the likelihood of "chatter" which will result in poor finish on the machined surface and reduce the life of the cutter. According to The Cincinnati Milling Machine Co., milling cutters used for general purpose work and having diameters from $\frac{1}{8}$ to 3 inches should have clearance angles from 13 to 5 degrees, respectively, decreasing proportionately as the diameter increases. General purpose cutters over 3 inches in diameter should be provided with a clearance angle of 4 to 5 degrees. The land width is usually $\frac{1}{64}$, $\frac{1}{32}$, and $\frac{1}{16}$ inch, respectively, for small, medium, and large cutters.

The primary clearance or relief angle for best results varies according to the material being milled about as follows: low carbon, high carbon, and alloy steels, 3 to 5 degrees; cast iron and medium and hard bronze, 4 to 7 degrees; brass, soft bronze, aluminum, magnesium, plastics, etc., 10 to 12 degrees. When milling cutters are resharpened, it is customary to grind a secondary clearance angle of 3 to 5 degrees behind the primary clearance angle to reduce the land width to its original value and thus avoid interference with the surface to be milled. A general formula for plain milling cutters, face mills, and form relieved cutters which gives the clearance angle C , in degrees, necessitated by the feed per revolution F , in inches, the width of land L , in inches, the depth of cut d , in inches, the cutter diameter D , in inches, and the Brinell hardness number B of the work being cut is:

$$C = \frac{45860}{DB} \left(1.5L + \frac{F}{\pi D} \sqrt{d(D-d)} \right)$$

Rake Angles for Milling Cutters.—In peripheral milling cutters, the rake angle is generally defined as the angle in degrees that the tooth face deviates from a radial line to the cutting edge. In face milling cutters, the teeth are inclined with respect to both the radial and axial lines. These angles are called *radial* and *axial* rake, respectively. The radial and axial rake angles may be positive, zero, or negative.

Positive rake angles should be used whenever possible for all types of high-speed steel milling cutters. For sintered carbide tipped cutters, zero and negative rake angles are frequently employed to provide more material back of the cutting edge to resist shock loads.

Rake Angles for High-speed Steel Cutters: Positive rake angles of 10 to 15 degrees are satisfactory for milling steels of various compositions with plain milling cutters. For softer materials such as magnesium and aluminum alloys, the rake angle may be 25 degrees or more. Metal slitting saws for cutting alloy steel usually have rake angles from 5 to 10 degrees, whereas zero and sometimes negative rake angles are used for saws to cut copper and other soft non-ferrous metals to reduce the tendency to "hog in." Form relieved cutters usually have rake angles of 0, 5, or 10 degrees. Commercial face milling cutters usually

have 10 degrees positive radial and axial rake angles for general use in milling cast iron, forged and alloy steel, brass, and bronze; for milling castings and forgings of magnesium and free-cutting aluminum and their alloys, the rake angles may be increased to 25 degrees positive or more, depending on the operating conditions; a smaller rake angle is used for abrasive or difficult to machine aluminum alloys.

Cast Non-ferrous Tool Material Milling Cutters: Positive rake angles are generally provided on milling cutters using cast non-ferrous tool materials although negative rake angles may be used advantageously for some operations such as those where shock loads are encountered or where it is necessary to eliminate vibration when milling thin sections.

Sintered Carbide Milling Cutters: Peripheral milling cutters such as slab mills, slotting cutters, saws, etc., tipped with sintered carbide, generally have negative radial rake angles of 5 degrees for soft low carbon steel and 10 degrees or more for alloy steels. Positive axial rake angles of 5 and 10 degrees, respectively, may be provided, and for slotting saws and cutters, 0 degree axial rake may be used. On soft materials such as free-cutting aluminum alloys, positive rake angles of 10 to so degrees are used. For milling abrasive or difficult to machine aluminum alloys, small positive or even negative rake angles are used.

Various Set-ups Used in Grinding the Clearance Angle on Milling Cutter Teeth

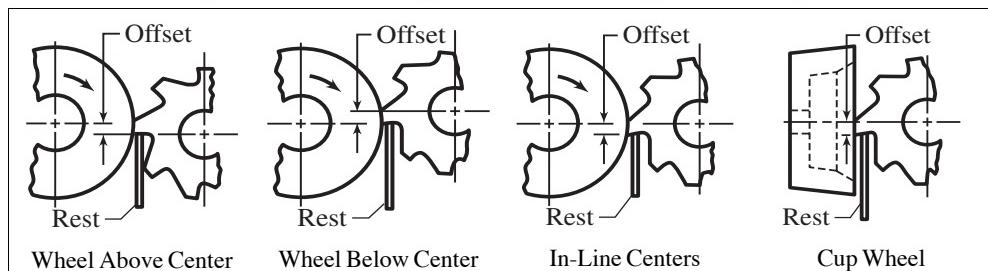


Table 2. Distance to Set Center of Wheel Above the Cutter Center (Disk Wheel)

| Dia.of Wheel, Inches | Desired Clearance Angle, Degrees | | | | | | | | | | | |
|----------------------------|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | ^a Distance to Offset Wheel Center Above Cutter Center, Inches | | | | | | | | | | | |
| 3 | 0.026 | 0.052 | 0.079 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.235 | 0.260 | 0.286 | 0.312 |
| 4 | 0.035 | 0.070 | 0.105 | 0.140 | 0.174 | 0.209 | 0.244 | 0.278 | 0.313 | 0.347 | 0.382 | 0.416 |
| 5 | 0.044 | 0.087 | 0.131 | 0.174 | 0.218 | 0.261 | 0.305 | 0.348 | 0.391 | 0.434 | 0.477 | 0.520 |
| 6 | 0.052 | 0.105 | 0.157 | 0.209 | 0.261 | 0.314 | 0.366 | 0.417 | 0.469 | 0.521 | 0.572 | 0.624 |
| 7 | 0.061 | 0.122 | 0.183 | 0.244 | 0.305 | 0.366 | 0.427 | 0.487 | 0.547 | 0.608 | 0.668 | 0.728 |
| 8 | 0.070 | 0.140 | 0.209 | 0.279 | 0.349 | 0.418 | 0.488 | 0.557 | 0.626 | 0.695 | 0.763 | 0.832 |
| 9 | 0.079 | 0.157 | 0.236 | 0.314 | 0.392 | 0.470 | 0.548 | 0.626 | 0.704 | 0.781 | 0.859 | 0.936 |
| 10 | 0.087 | 0.175 | 0.262 | 0.349 | 0.436 | 0.523 | 0.609 | 0.696 | 0.782 | 0.868 | 0.954 | 10.040 |

^aCalculated from the formula: Offset = Cutter Diameter $\times \frac{1}{2} \times \text{Sine of Clearance Angle}$.

Table 3. Distance to Set Center of Wheel Below the Cutter Center (Disk Wheel)

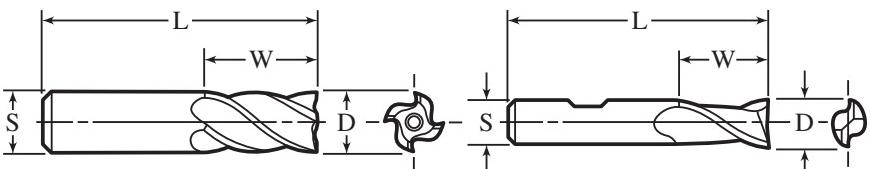
| Dia.of Cutter, Inches | Desired Clearance Angle, Degrees | | | | | | | | | | | |
|-----------------------------|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | ^a Distance to Offset Wheel Center Below Cutter Center, Inches | | | | | | | | | | | |
| 2 | 0.017 | 0.035 | 0.052 | 0.070 | 0.087 | 0.105 | 0.122 | 0.139 | 0.156 | 0.174 | 0.191 | 0.208 |
| 3 | 0.026 | 0.052 | 0.079 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.235 | 0.260 | 0.286 | 0.312 |
| 4 | 0.035 | 0.070 | 0.105 | 0.140 | 0.174 | 0.209 | 0.244 | 0.278 | 0.313 | 0.347 | 0.382 | 0.416 |
| 5 | 0.044 | 0.087 | 0.131 | 0.174 | 0.218 | 0.261 | 0.305 | 0.348 | 0.391 | 0.434 | 0.477 | 0.520 |
| 6 | 0.052 | 0.105 | 0.157 | 0.209 | 0.261 | 0.314 | 0.366 | 0.417 | 0.469 | 0.521 | 0.572 | 0.624 |
| 7 | 0.061 | 0.122 | 0.183 | 0.244 | 0.305 | 0.366 | 0.427 | 0.487 | 0.547 | 0.608 | 0.668 | 0.728 |
| 8 | 0.070 | 0.140 | 0.209 | 0.279 | 0.349 | 0.418 | 0.488 | 0.557 | 0.626 | 0.695 | 0.763 | 0.832 |
| 9 | 0.079 | 0.157 | 0.236 | 0.314 | 0.392 | 0.470 | 0.548 | 0.626 | 0.704 | 0.781 | 0.859 | 0.936 |
| 10 | 0.087 | 0.175 | 0.262 | 0.349 | 0.436 | 0.523 | 0.609 | 0.696 | 0.782 | 0.868 | 0.954 | 10.040 |

Distance to Set Tooth Rest Below Center Line of Wheel and Cutter.—When the clearance angle is ground with a disk type wheel by keeping the center line of the wheel in line with the center line of the cutter, the tooth rest should be lowered by an amount given by the following formula:

$$\text{Offset} = \frac{\text{Wheel Diam.} \times \text{Cutter Diam.} \times \text{Sine of One-half the Clearance Angle}}{\text{Wheel Diam.} + \text{Cutter Diam.}}$$

Distance to Set Tooth Rest Below Cutter Center When Cup Wheel is Used.—When the clearance is ground with a cup wheel, the tooth rest is set below the center of the cutter the same amount as given in the table for "Distance to Set Center of Wheel Below the Cutter Center (Disk Wheel)."

Table 4. ANSI Multiple- and Two-Flute Single-End Helical End Mills with Plain, Straight, and Weldon Shanks ANSI/ASME B94.19-1997, R2003



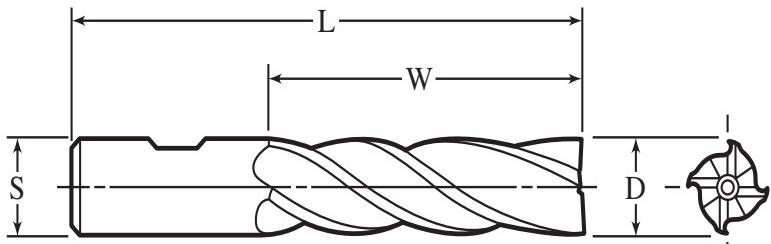
| Cutter Diameter, <i>D</i> | | | Shank Diameter, <i>S</i> | | Length of Cut, <i>W</i> | Length Overall, <i>L</i> |
|---|--------|--------|-----------------------------|--------|-------------------------------|--------------------------------|
| Nom. | Max. | Min. | Max. | Min. | | |
| Multiple-flute with Plain Straight Shanks | | | | | | |
| $\frac{1}{8}$ | 0.128 | 0.125 | 0.125 | 0.1245 | $\frac{5}{16}$ | $1\frac{1}{4}$ |
| $\frac{3}{16}$ | 0.1905 | 0.1875 | 0.1875 | 0.1870 | $\frac{1}{2}$ | $1\frac{3}{8}$ |
| $\frac{1}{4}$ | 0.253 | 0.250 | 0.250 | 0.2495 | $\frac{5}{8}$ | $1\frac{11}{16}$ |
| $\frac{3}{8}$ | 0.378 | 0.375 | 0.375 | 0.3745 | $\frac{3}{4}$ | $1\frac{13}{16}$ |
| $\frac{1}{2}$ | 0.503 | 0.500 | 0.500 | 0.4995 | $1\frac{5}{16}$ | $2\frac{1}{4}$ |
| $\frac{3}{4}$ | 0.752 | 0.750 | 0.750 | 0.7495 | $1\frac{1}{4}$ | $2\frac{5}{8}$ |
| Two-flute for Keyway Cutting with Weldon Shanks | | | | | | |
| $\frac{1}{8}$ | 0.125 | 0.1235 | 0.3749 | 0.3745 | $\frac{3}{8}$ | $2\frac{5}{16}$ |
| $\frac{3}{16}$ | 0.1875 | 0.1860 | 0.3749 | 0.3745 | $\frac{7}{16}$ | $2\frac{5}{16}$ |
| $\frac{1}{4}$ | 0.250 | 0.2485 | 0.3749 | 0.3745 | $\frac{1}{2}$ | $2\frac{5}{16}$ |
| $\frac{5}{16}$ | 0.3125 | 0.3110 | 0.3749 | 0.3745 | $\frac{9}{16}$ | $2\frac{5}{16}$ |
| $\frac{3}{8}$ | 0.375 | 0.3735 | 0.3749 | 0.3745 | $\frac{9}{16}$ | $2\frac{5}{16}$ |
| $\frac{1}{2}$ | 0.500 | 0.4985 | 0.4999 | 0.4995 | 1 | 3 |
| $\frac{5}{8}$ | 0.625 | 0.6235 | 0.6249 | 0.6245 | $1\frac{5}{16}$ | $3\frac{7}{16}$ |
| $\frac{3}{4}$ | 0.750 | 0.7485 | 0.7499 | 0.7495 | $1\frac{5}{16}$ | $3\frac{7}{16}$ |
| $\frac{7}{8}$ | 0.875 | 0.8735 | 0.8749 | 0.8745 | $1\frac{1}{2}$ | $3\frac{3}{4}$ |
| 1 | 1.000 | 0.9985 | 0.9999 | 0.9995 | $1\frac{5}{8}$ | $4\frac{1}{8}$ |
| $1\frac{1}{4}$ | 1.250 | 1.2485 | 1.2499 | 1.2495 | $1\frac{5}{8}$ | $4\frac{1}{8}$ |
| $1\frac{1}{2}$ | 1.500 | 1.4985 | 1.2499 | 1.2495 | $1\frac{5}{8}$ | $4\frac{1}{8}$ |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters with right-hand helix are standard.

The helix angle is not less than 10 degrees for multiple-flute cutters with plain straight shanks; the helix angle is optional with the manufacturer for two-flute cutters with Weldon shanks.

Tolerances: On $W, \pm\frac{1}{32}$ inch; on $L, \pm\frac{1}{16}$ inch.

Table 5. ANSI Regular-, Long-, and Extra Long-Length, Multiple-Flute Medium Helix Single-End End Mills with Weldon Shanks ANSI/ASME B94.19-1997, R2003



| Cutter Dia., <i>D</i> | Regular Mills | | | Long Mills | | | Extra Long Mills | | | | | |
|-----------------------------|----------------|----------------|------------------|-----------------------|----------------|----------------|------------------|-----------------------|----------------|----------------|-----------------|-----------------------|
| <i>D</i> | <i>S</i> | <i>W</i> | <i>L</i> | <i>N</i> ^a | <i>S</i> | <i>W</i> | <i>L</i> | <i>N</i> ^a | <i>S</i> | <i>W</i> | <i>L</i> | <i>N</i> ^a |
| $\frac{1}{8}$ ^b | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{5}{16}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{3}{16}$ ^b | $\frac{3}{8}$ | $\frac{1}{2}$ | $2\frac{7}{8}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{1}{4}$ ^b | $\frac{3}{8}$ | $\frac{5}{8}$ | $2\frac{7}{16}$ | 4 | $\frac{3}{8}$ | $1\frac{1}{4}$ | $3\frac{5}{16}$ | 4 | $\frac{3}{8}$ | $1\frac{3}{4}$ | $3\frac{9}{16}$ | 4 |
| $\frac{5}{16}$ ^b | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | 4 | $\frac{3}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{8}$ | 4 | $\frac{3}{8}$ | 2 | $3\frac{3}{4}$ | 4 |
| $\frac{3}{8}$ ^b | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | 4 | $\frac{3}{8}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | 4 | $\frac{3}{8}$ | $2\frac{1}{2}$ | $4\frac{1}{4}$ | 4 |
| $\frac{7}{16}$ | $\frac{3}{8}$ | 1 | $2\frac{11}{16}$ | 4 | $\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{3}{4}$ | 4 | ... | ... | ... | ... |
| $\frac{1}{2}$ | $\frac{3}{8}$ | 1 | $2\frac{11}{16}$ | 4 | $\frac{1}{2}$ | 2 | 4 | 4 | $\frac{1}{2}$ | 3 | 5 | 4 |
| $\frac{1}{2}$ ^b | $\frac{1}{2}$ | $1\frac{1}{4}$ | $3\frac{1}{4}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{9}{16}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | 4 | $\frac{5}{8}$ | $2\frac{1}{2}$ | $4\frac{5}{8}$ | 4 | $\frac{5}{8}$ | 4 | $6\frac{1}{8}$ | 4 |
| $\frac{11}{16}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{3}{4}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | 4 | $\frac{3}{4}$ | 3 | $5\frac{1}{4}$ | 4 | $\frac{3}{4}$ | 4 | $6\frac{1}{4}$ | 4 |
| $\frac{5}{8}$ ^b | $\frac{5}{8}$ | $1\frac{3}{8}$ | $3\frac{3}{4}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{13}{16}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | $3\frac{3}{4}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{7}{8}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | 4 | 6 | ... | ... | ... | ... | ... | ... | ... | ... |
| $\frac{1}{2}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | 4 | 6 | $\frac{7}{8}$ | $3\frac{1}{2}$ | $5\frac{3}{4}$ | 4 | $\frac{7}{8}$ | 5 | $7\frac{1}{4}$ | 4 |
| 1 | $\frac{5}{8}$ | $1\frac{3}{8}$ | 4 | 6 | 1 | 4 | $6\frac{1}{2}$ | 4 | 1 | 6 | $8\frac{1}{2}$ | 4 |
| $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $4\frac{1}{8}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| 1 | $\frac{7}{8}$ | $1\frac{3}{8}$ | $4\frac{1}{8}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $1\frac{1}{8}$ | $\frac{7}{8}$ | 2 | $4\frac{1}{4}$ | 6 | 1 | 4 | $6\frac{1}{2}$ | 6 | ... | ... | ... | ... |
| $1\frac{1}{4}$ | $\frac{7}{8}$ | 2 | $4\frac{1}{4}$ | 6 | 1 | 4 | $6\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | 6 | $8\frac{1}{2}$ | 6 |
| 1 | 1 | 2 | $4\frac{1}{2}$ | 4 | ... | ... | ... | ... | ... | ... | ... | ... |
| $1\frac{1}{8}$ | 1 | 2 | $4\frac{1}{2}$ | 6 | ... | ... | ... | ... | ... | ... | ... | ... |
| $1\frac{1}{4}$ | 1 | 2 | $4\frac{1}{2}$ | 6 | ... | ... | ... | ... | ... | ... | ... | ... |
| $1\frac{3}{8}$ | 1 | 2 | $4\frac{1}{2}$ | 6 | ... | ... | ... | ... | ... | ... | ... | ... |
| $1\frac{1}{2}$ | 1 | 2 | $4\frac{1}{2}$ | 6 | 1 | 4 | $6\frac{1}{2}$ | 6 | ... | ... | ... | ... |
| $1\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | 6 | ... | ... | ... | ... |
| $1\frac{1}{2}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | 8 | $10\frac{1}{2}$ | 6 |
| $1\frac{3}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | 6 | ... | ... | ... | ... |
| 2 | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | 8 | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | 8 | ... | ... | ... | ... |

^a*N* = Number of flutes.

^bIn this size of regular mill a left-hand cutter with left-hand helix is also standard.

All dimensions are in inches. All cutters are high-speed steel. Helix angle is greater than 19 degrees but not more than 39 degrees. Right-hand cutters with right-hand helix are standard.

As indicated in the table, shank diameter *S* may be larger, smaller, or the same as the cutter diameter *D*.

Tolerances: On *D*, +0.003 inch; on *S*, -0.0001 to -0.0005 inch; on *W*, $\pm\frac{1}{32}$ inch; on *L*, $\pm\frac{1}{16}$ inch.

Table 6. American National Standard Form Relieved Corner Rounding Cutters with Weldon Shanks ANSI/ASME B94.19-1997, R2003

| Rad., <i>R</i> | Dia., <i>D</i> | Dia., <i>d</i> | <i>S</i> | <i>L</i> | Rad., <i>R</i> | Dia., <i>D</i> | Dia., <i>d</i> | <i>S</i> | <i>L</i> |
|-------------------|-------------------|-------------------|---------------|----------------|-------------------|-------------------|-------------------|---------------|----------------|
| $\frac{1}{16}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $3\frac{1}{2}$ |
| $\frac{3}{32}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{1}{2}$ | $\frac{3}{16}$ | $\frac{7}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | $3\frac{1}{8}$ |
| $\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | 3 | $\frac{1}{4}$ | 1 | $\frac{3}{8}$ | $\frac{3}{4}$ | $3\frac{1}{4}$ |
| $\frac{5}{32}$ | $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{1}{2}$ | 3 | $\frac{5}{16}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | $3\frac{1}{2}$ |
| $\frac{3}{16}$ | $\frac{7}{8}$ | $\frac{5}{16}$ | $\frac{1}{2}$ | 3 | $\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | $3\frac{3}{4}$ |
| $\frac{1}{4}$ | 1 | $\frac{3}{8}$ | $\frac{1}{2}$ | 3 | $\frac{7}{16}$ | $1\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | 4 |
| $\frac{5}{16}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $3\frac{1}{4}$ | $\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | 1 | $4\frac{1}{8}$ |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters are standard.

Tolerances: On D , ± 0.010 inch; on diameter of circle, $2R$, ± 0.001 inch for cutters up to and including $\frac{1}{8}$ -inch radius, $+0.002, -0.001$ inch for cutters over $\frac{1}{8}$ -inch radius; on S , -0.0001 to -0.0005 inch; and on L , $\pm \frac{1}{16}$ inch.

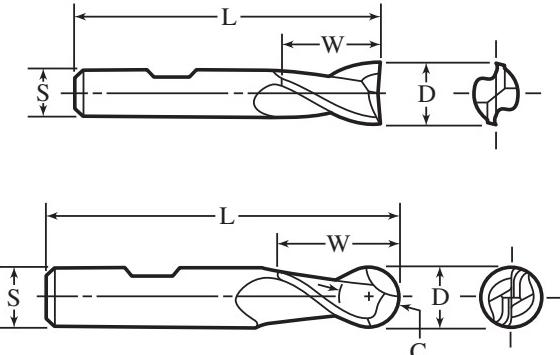
Table 7. ANSI Two-Flute, High Helix, Regular-, Long-, and Extra Long-Length, Single-End End Mills with Weldon Shanks ANSI/ASME B94.19-1997, R2003

| Cutter Dia., <i>D</i> | Regular Mill | | | Long Mill | | | Extra Long Mill | | |
|-----------------------------|----------------|----------------|-----------------|----------------|----------------|-----------------|-----------------|----------------|-----------------|
| | <i>S</i> | <i>W</i> | <i>L</i> | <i>S</i> | <i>W</i> | <i>L</i> | <i>S</i> | <i>W</i> | <i>L</i> |
| $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $2\frac{7}{16}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{16}$ | $\frac{3}{8}$ | $1\frac{3}{4}$ | $3\frac{1}{16}$ |
| $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{8}$ | $\frac{3}{8}$ | 2 | $3\frac{3}{4}$ |
| $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{1}{2}$ | $4\frac{1}{4}$ |
| $\frac{7}{16}$ | $\frac{3}{8}$ | 1 | $2\frac{1}{16}$ | $\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{3}{4}$ | ... | ... | ... |
| $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $3\frac{3}{4}$ | $\frac{1}{2}$ | 2 | 4 | $\frac{1}{2}$ | 3 | 5 |
| $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{1}{8}$ | $3\frac{3}{4}$ | $\frac{5}{8}$ | $2\frac{1}{2}$ | $4\frac{5}{8}$ | $\frac{5}{8}$ | 4 | $6\frac{1}{8}$ |
| $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $3\frac{7}{8}$ | $\frac{3}{4}$ | 3 | $5\frac{1}{4}$ | $\frac{3}{4}$ | 4 | $6\frac{1}{4}$ |
| $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $4\frac{1}{8}$ | ... | ... | ... | ... | ... | ... |
| 1 | 1 | 2 | $4\frac{1}{2}$ | 1 | 4 | $6\frac{1}{2}$ | 1 | 6 | $8\frac{1}{2}$ |
| $1\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | $1\frac{1}{4}$ | 6 | $8\frac{1}{2}$ |
| $1\frac{1}{2}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | $1\frac{1}{4}$ | 8 | $10\frac{1}{2}$ |
| 2 | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | ... | ... | ... |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters with right-hand helix are standard. Helix angle is greater than 39 degrees.

Tolerances: On D , $+0.003$ inch; on S , -0.0001 to -0.0005 inch; on W , $\pm \frac{1}{32}$ inch; and on L , $\pm \frac{1}{16}$ inch.

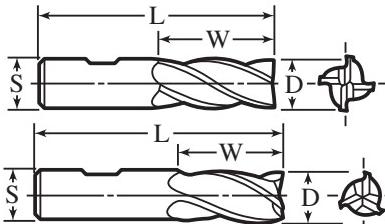
Table 8. ANSI Stub- and Regular-Length, Two-Flute, Medium Helix, Plain- and Ball-End, Single-End End Mills with Weldon Shanks
ANSI/ASME B94.19-1997, R2003



| Regular Length — Plain End | | | | Stub Length — Plain End | | | |
|----------------------------|----------------|-----------------|------------------|-------------------------|------------------|------------------------|-----------------------|
| Dia., D | S | W | L | Cutter Dia., D | Shank Dia., S | Length of Cut. W | Length Over- all,L |
| $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{5}{16}$ | $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $2\frac{1}{8}$ |
| $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $2\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{9}{32}$ | $2\frac{3}{16}$ |
| $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $2\frac{7}{16}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{1}{4}$ |
| $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{9}{16}$ | $2\frac{1}{2}$ | | | | |
| $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{9}{16}$ | $2\frac{1}{2}$ | | | | |
| $\frac{7}{16}$ | $\frac{3}{8}$ | $1\frac{3}{16}$ | $2\frac{11}{16}$ | | | | |
| $\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{3}{16}$ | $2\frac{11}{16}$ | | | | |
| $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | $3\frac{1}{4}$ | | | | |
| $\frac{9}{16}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{3}{8}$ | | | | |
| $\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{3}{8}$ | | | | |
| $\frac{11}{16}$ | $\frac{1}{2}$ | $1\frac{5}{16}$ | $3\frac{5}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $2\frac{3}{8}$ |
| $\frac{3}{4}$ | $\frac{1}{2}$ | $1\frac{5}{16}$ | $3\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{7}{16}$ |
| $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | $3\frac{3}{4}$ | | | | |
| $\frac{11}{16}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | $3\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ |
| $\frac{3}{4}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | $3\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ |
| $\frac{13}{16}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ | 4 | $\frac{7}{16}$ | $\frac{1}{2}$ | 1 | 3 |
| $\frac{7}{8}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ | 4 | $\frac{7}{16}$ | $\frac{1}{2}$ | | |
| 1 | $\frac{5}{8}$ | $1\frac{1}{2}$ | 4 | $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | 3 |
| $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{1}{2}$ | $4\frac{1}{8}$ | $\frac{9}{16}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{1}{8}$ |
| 1 | $\frac{7}{8}$ | $1\frac{1}{2}$ | $4\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{1}{8}$ |
| $1\frac{1}{8}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $4\frac{1}{4}$ | | | | |
| $1\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $4\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{2}$ |
| 1 | 1 | $1\frac{1}{8}$ | $4\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $1\frac{3}{16}$ | $3\frac{5}{16}$ |
| $1\frac{1}{8}$ | 1 | $1\frac{1}{8}$ | $4\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{3}{8}$ | $3\frac{7}{8}$ |
| $1\frac{1}{4}$ | 1 | $1\frac{1}{8}$ | $4\frac{1}{2}$ | | | | |
| $1\frac{3}{8}$ | 1 | $1\frac{5}{8}$ | $4\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{7}{8}$ | 2 | $4\frac{1}{4}$ |
| $1\frac{1}{2}$ | 1 | $1\frac{5}{8}$ | $4\frac{1}{2}$ | 1 | 1 | $2\frac{1}{4}$ | $4\frac{1}{4}$ |
| $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $4\frac{1}{2}$ | $1\frac{1}{8}$ | 1 | $2\frac{1}{4}$ | $4\frac{3}{4}$ |
| $1\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $4\frac{1}{2}$ | | | | |
| $1\frac{3}{4}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $4\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | 5 |
| 2 | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $4\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | 5 |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters with right-hand helix are standard. Helix angle is greater than 19 degrees but not more than 39 degrees. *Tolerances:* On C and D, -0.0015 inch for stub-length mills, $+0.003$ inch for regular-length mills; on S, -0.0001 to -0.0005 inch; on W, $\pm \frac{1}{32}$ inch; and on L, $\pm \frac{1}{16}$ inch. The following single-end end mills are available in premium high speed steel: ball end, two flute, with D ranging from $\frac{1}{8}$ to $1\frac{1}{2}$ inches; ball end, multiple flute, with D ranging from $\frac{1}{8}$ to 1 inch; and plain end, two flute, with D ranging from $\frac{1}{8}$ to $1\frac{1}{2}$ inches.

Table 9. American National Standard Regular-, Long-, and Extra Long-Length, Three- and Four-Flute, Medium Helix, Center Cutting, Single-End End Mills with Weldon Shanks ANSI/ASME B94.19-1997, R2003



| Dia., <i>D</i> | Regular Length | | | Long Length | | | Extra Long Length | | |
|-------------------|----------------|----------------|-----------------|----------------|----------------|-----------------|-------------------|----------------|-----------------|
| | <i>S</i> | <i>W</i> | <i>L</i> | <i>S</i> | <i>W</i> | <i>L</i> | <i>S</i> | <i>W</i> | <i>L</i> |
| $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{5}{16}$ | ... | ... | ... | ... | ... | ... |
| $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $2\frac{3}{8}$ | ... | ... | ... | ... | ... | ... |
| $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $2\frac{7}{16}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{16}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{16}$ |
| $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{8}$ | $\frac{3}{8}$ | 2 | $3\frac{3}{4}$ |
| $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{1}{2}$ | $4\frac{1}{4}$ |
| $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $3\frac{1}{4}$ | $\frac{1}{2}$ | 2 | 4 | $\frac{1}{2}$ | 3 | 5 |
| $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{5}{8}$ | $3\frac{3}{4}$ | $\frac{5}{8}$ | $2\frac{1}{2}$ | $4\frac{5}{8}$ | $\frac{5}{8}$ | 4 | $6\frac{1}{8}$ |
| $1\frac{1}{16}$ | $\frac{5}{8}$ | $1\frac{5}{8}$ | $3\frac{3}{4}$ | ... | ... | ... | ... | ... | ... |
| $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{5}{8}$ | $3\frac{7}{8}$ | $\frac{3}{4}$ | 3 | $5\frac{1}{4}$ | $\frac{3}{4}$ | 4 | $6\frac{1}{4}$ |
| $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{7}{8}$ | $4\frac{1}{8}$ | $\frac{7}{8}$ | $3\frac{1}{2}$ | $5\frac{3}{4}$ | $\frac{7}{8}$ | 5 | $7\frac{1}{4}$ |
| 1 | 1 | 2 | $4\frac{1}{2}$ | 1 | 4 | $6\frac{1}{2}$ | 1 | 6 | $8\frac{1}{2}$ |
| $1\frac{1}{8}$ | 1 | 2 | $4\frac{1}{2}$ | ... | ... | ... | ... | ... | ... |
| $1\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | $1\frac{1}{4}$ | 6 | $8\frac{1}{2}$ |
| $1\frac{1}{2}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | ... | ... | ... | ... | ... | ... |

| Dia., <i>D</i> | <i>S</i> | <i>W</i> | <i>L</i> | Dia., <i>D</i> | Regular Length (cont.) | | | |
|----------------|---------------|----------------|------------------|----------------|------------------------|----------------|-----------------|-------------|
| | | | | | <i>S</i> | <i>W</i> | <i>L</i> | Long Length |
| $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{5}{16}$ | $1\frac{1}{8}$ | 1 | 2 | $4\frac{1}{2}$ | |
| $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $2\frac{3}{8}$ | $1\frac{1}{4}$ | 1 | 2 | $4\frac{1}{2}$ | |
| $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $2\frac{7}{16}$ | $1\frac{1}{2}$ | 1 | 2 | $4\frac{1}{2}$ | |
| $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | |
| $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | |
| $\frac{7}{16}$ | $\frac{3}{8}$ | 1 | $2\frac{11}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | |
| $\frac{1}{2}$ | $\frac{3}{8}$ | 1 | $2\frac{1}{16}$ | 2 | $1\frac{1}{4}$ | 2 | $4\frac{1}{2}$ | |
| $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $3\frac{1}{4}$ | | | | | |
| $\frac{3}{16}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{16}$ | |
| $\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{8}$ | |
| $\frac{3}{4}$ | $\frac{1}{2}$ | $1\frac{5}{8}$ | $3\frac{5}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | |
| $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{5}{8}$ | $3\frac{3}{4}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{3}{4}$ | |
| $\frac{3}{4}$ | $\frac{5}{8}$ | $1\frac{5}{8}$ | $3\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | 2 | 4 | |
| $\frac{7}{8}$ | $\frac{5}{8}$ | $1\frac{7}{8}$ | 4 | $\frac{5}{8}$ | $\frac{5}{8}$ | $2\frac{1}{2}$ | $4\frac{1}{8}$ | |
| 1 | $\frac{5}{8}$ | $1\frac{7}{8}$ | 4 | $\frac{3}{4}$ | $\frac{3}{4}$ | 3 | $5\frac{1}{4}$ | |
| $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | 1 | 1 | 4 | $6\frac{1}{2}$ | |
| $\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{3}{8}$ | $4\frac{1}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | |
| 1 | $\frac{3}{4}$ | $1\frac{3}{8}$ | $4\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | |
| 1 | $\frac{7}{8}$ | $1\frac{7}{8}$ | $4\frac{1}{8}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | |
| 1 | 1 | 2 | $4\frac{1}{2}$ | 2 | $1\frac{1}{4}$ | 4 | $6\frac{1}{2}$ | |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters with right-hand helix are standard. Helix angle is greater than 19 degrees but not more than 39 degrees. *Tolerances:* On *D*, $+0.003$ inch; on *S*, -0.0001 to -0.0005 inch; on *W*, $\pm\frac{1}{32}$ inch; and on *L*, $\pm\frac{1}{16}$ inch. The following center-cutting, single-end end mills are available in premium high speed steel: regular length, multiple flute, with *D* ranging from $\frac{1}{8}$ to $1\frac{1}{2}$ inches; long length, multiple flute, with *D* ranging from $\frac{3}{8}$ to $1\frac{1}{4}$ inches; and extra long-length, multiple flute, with *D* ranging from $\frac{3}{8}$ to $1\frac{1}{4}$ inches.

Table 10. American National Standard 60-Degree Single-Angle Milling Cutters with Weldon Shanks ANSI/ASME B94.19-1985, R2003

| Dia., D | S | W | L | Dia., D | S | W | L |
|----------------|---------------|----------------|----------------|----------------|---------------|-----------------|----------------|
| $\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{5}{16}$ | $2\frac{1}{8}$ | $1\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{3}{16}$ | $3\frac{1}{4}$ |
| $1\frac{3}{8}$ | $\frac{5}{8}$ | $\frac{9}{16}$ | $2\frac{7}{8}$ | $2\frac{1}{4}$ | 1 | $1\frac{1}{16}$ | $3\frac{3}{4}$ |

All dimensions are in inches. All cutters are high-speed steel. Right-hand cutters are standard.

Tolerances: On $D, \pm 0.015$ inch; on $S, -0.0001$ to -0.0005 inch; on $W, \pm 0.015$ inch; and on $L, \pm \frac{1}{16}$ inch.

Table 11. Key Size Versus Shaft Diameter ANSI B17.1-1967, R2003

| Nominal Shaft Diameter | | Nominal Key Size | | | Normal Keyseat Depth | |
|------------------------|----------------|------------------|----------------|------------------|----------------------|----------------|
| Over | To (Incl.) | Width, W | Height, H | | H/2 | |
| | | | Square | Rectangular | Square | Rectangular |
| $\frac{5}{16}$ | $\frac{7}{16}$ | $\frac{3}{32}$ | $\frac{3}{32}$ | ... | $\frac{3}{64}$ | ... |
| $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{32}$ | $\frac{1}{16}$ | $\frac{3}{64}$ |
| $\frac{9}{16}$ | $\frac{7}{8}$ | $\frac{3}{16}$ | $\frac{3}{16}$ | $\frac{1}{8}$ | $\frac{3}{32}$ | $\frac{1}{16}$ |
| $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | $\frac{1}{8}$ | $\frac{3}{32}$ |
| $1\frac{1}{4}$ | $1\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ |
| $1\frac{3}{8}$ | $1\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | $\frac{1}{8}$ |
| $1\frac{3}{4}$ | $2\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{3}{16}$ |
| $2\frac{1}{4}$ | $2\frac{3}{4}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{7}{16}$ | $\frac{5}{16}$ | $\frac{7}{32}$ |
| $2\frac{3}{4}$ | $3\frac{1}{4}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{1}{4}$ |
| $3\frac{1}{4}$ | $3\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{7}{8}$ | $\frac{5}{8}$ | $\frac{7}{16}$ | $\frac{5}{16}$ |
| $3\frac{3}{4}$ | $4\frac{1}{2}$ | 1 | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{8}$ |
| $4\frac{1}{2}$ | $5\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{5}{8}$ | $\frac{7}{16}$ |
| $5\frac{1}{2}$ | $6\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ |
| $6\frac{1}{2}$ | $7\frac{1}{2}$ | $1\frac{3}{4}$ | $1\frac{3}{4}$ | $1\frac{1}{2}^a$ | $\frac{7}{8}$ | $\frac{3}{4}$ |
| $7\frac{1}{2}$ | 9 | 2 | 2 | $1\frac{1}{2}$ | 1 | $\frac{3}{4}$ |
| 9 | 11 | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ |

^aSome key standards show $1\frac{1}{4}$ inches; preferred height is $1\frac{1}{2}$ inches.

All dimensions are given in inches. For larger shaft sizes, see *ANSI Standard Woodruff Keys and Keyseats*.

Square keys preferred for shaft diameters above heavy line; rectangular keys, below.

Table 12. American National Standard Keys and Keyways for Milling Cutters and Arbors ANSI/ASME B94.19-1997, R2003

| | | Arbor and Keyseat | | | | Cutter Hole and Keyway | | | | Arbor and Key | | | | |
|---|---------------------------------|-------------------|-----------|-----------|-----------|------------------------|-----------|------------------------|----------------|------------------|-----------|-----------|-----------|-----------|
| Nom. Arbor and Cutter Hole Dia. | Nom. Size Key (Square) | Arbor and Keyseat | | | | Hole and Keyway | | | | Arbor and Key | | | | |
| | | A Max. | A Min. | B Max. | B Min. | C Max. | C Min. | D ^a Min. | H Nom. | Corner Radius | E Max. | E Min. | F Max. | F Min. |
| $\frac{1}{2}$ | $\frac{3}{32}$ | 0.0947 | 0.0937 | 0.4531 | 0.4481 | 0.106 | 0.099 | 0.5578 | $\frac{3}{64}$ | 0.020 | 0.0932 | 0.0927 | 0.5468 | 0.5408 |
| $\frac{5}{8}$ | $\frac{1}{8}$ | 0.1260 | 0.1250 | 0.5625 | 0.5575 | 0.137 | 0.130 | 0.6985 | $\frac{1}{16}$ | $\frac{1}{32}$ | 0.1245 | 0.1240 | 0.6875 | 0.6815 |
| $\frac{3}{4}$ | $\frac{1}{8}$ | 0.1260 | 0.1250 | 0.6875 | 0.6825 | 0.137 | 0.130 | 0.8225 | $\frac{1}{16}$ | $\frac{1}{32}$ | 0.1245 | 0.1240 | 0.8125 | 0.8065 |
| $\frac{7}{8}$ | $\frac{1}{8}$ | 0.1260 | 0.1250 | 0.8125 | 0.8075 | 0.137 | 0.130 | 0.9475 | $\frac{1}{16}$ | $\frac{1}{32}$ | 0.1245 | 0.1240 | 0.9375 | 0.9315 |
| 1 | $\frac{1}{4}$ | 0.2510 | 0.2500 | 0.8438 | 0.8388 | 0.262 | 0.255 | 1.1040 | $\frac{3}{32}$ | $\frac{3}{64}$ | 0.2495 | 0.2490 | 1.0940 | 1.0880 |
| $1\frac{1}{4}$ | $\frac{5}{16}$ | 0.3135 | 0.3125 | 1.0630 | 1.0580 | 0.343 | 0.318 | 1.3850 | $\frac{1}{8}$ | $\frac{1}{16}$ | 0.3120 | 0.3115 | 1.3750 | 1.3690 |
| $1\frac{1}{2}$ | $\frac{3}{8}$ | 0.3760 | 0.3750 | 1.2810 | 1.2760 | 0.410 | 0.385 | 1.6660 | $\frac{5}{32}$ | $\frac{1}{16}$ | 0.3745 | 0.3740 | 1.6560 | 1.6500 |
| $1\frac{3}{4}$ | $\frac{7}{16}$ | 0.4385 | 0.4375 | 1.5000 | 1.4950 | 0.473 | 0.448 | 1.9480 | $\frac{3}{16}$ | $\frac{1}{16}$ | 0.4370 | 0.4365 | 1.9380 | 1.9320 |
| 2 | $\frac{1}{2}$ | 0.5010 | 0.5000 | 1.6870 | 1.6820 | 0.535 | 0.510 | 2.1980 | $\frac{3}{16}$ | $\frac{1}{16}$ | 0.4995 | 0.4990 | 2.1880 | 2.1820 |
| $2\frac{1}{2}$ | $\frac{5}{8}$ | 0.6260 | 0.6250 | 2.0940 | 2.0890 | 0.660 | 0.635 | 2.7330 | $\frac{7}{32}$ | $\frac{1}{16}$ | 0.6245 | 0.6240 | 2.7180 | 2.7120 |
| 3 | $\frac{3}{4}$ | 0.7510 | 0.7500 | 2.5000 | 2.4950 | 0.785 | 0.760 | 3.2650 | $\frac{1}{4}$ | $\frac{3}{32}$ | 0.7495 | 0.7490 | 3.2500 | 3.2440 |
| $3\frac{1}{2}$ | $\frac{7}{8}$ | 0.8760 | 0.8750 | 3.0000 | 2.9950 | 0.910 | 0.885 | 3.8900 | $\frac{3}{8}$ | $\frac{3}{32}$ | 0.8745 | 0.8740 | 3.8750 | 3.8690 |
| 4 | 1 | 1.0010 | 1.0000 | 3.3750 | 3.3700 | 1.035 | 1.010 | 4.3900 | $\frac{3}{8}$ | $\frac{3}{32}$ | 0.9995 | 0.9990 | 4.3750 | 4.3690 |
| $4\frac{1}{2}$ | $\frac{1}{8}$ | 1.1260 | 1.1250 | 3.8130 | 3.8080 | 1.160 | 1.135 | 4.9530 | $\frac{7}{16}$ | $\frac{1}{8}$ | 1.1245 | 1.1240 | 4.9380 | 4.9320 |
| 5 | $1\frac{1}{4}$ | 1.2510 | 1.2500 | 4.2500 | 4.2450 | 1.285 | 1.260 | 5.5150 | $\frac{1}{2}$ | $\frac{1}{8}$ | 1.2495 | 1.2490 | 5.5000 | 5.4940 |

^aD max. is 0.010 inch larger than D min.

All dimensions given in inches.

Table 13. American National Standard Woodruff Keyseat Cutters—Shank-Type Straight-Teeth and Arbor-Type Staggered-Teeth ANSI/ASME B94.19-1997, R2003

| Shank-type Cutters | | | | | | | | | | | |
|--------------------|------------------------|------------------|-------------------|---------------|------------------------|------------------|-------------------|---------------|------------------------|------------------|------------------|
| Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Length Overall, L | Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Length Overall, L | Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Length Overll, L |
| 202 | $\frac{1}{4}$ | $\frac{1}{16}$ | $2\frac{1}{16}$ | 506 | $\frac{3}{4}$ | $\frac{5}{32}$ | $2\frac{5}{32}$ | 809 | $1\frac{1}{8}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ |
| 202½ | $\frac{5}{16}$ | $\frac{1}{16}$ | $2\frac{1}{16}$ | 606 | $\frac{3}{4}$ | $\frac{5}{16}$ | $2\frac{3}{16}$ | 1009 | $1\frac{1}{8}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ |
| 302½ | $\frac{5}{16}$ | $\frac{3}{32}$ | $2\frac{3}{32}$ | 806 | $\frac{3}{4}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ | 610 | $1\frac{1}{4}$ | $\frac{5}{16}$ | $2\frac{3}{16}$ |
| 203 | $\frac{3}{8}$ | $\frac{1}{16}$ | $2\frac{1}{16}$ | 507 | $\frac{7}{8}$ | $\frac{5}{32}$ | $2\frac{5}{32}$ | 710 | $1\frac{1}{4}$ | $\frac{7}{32}$ | $2\frac{7}{32}$ |
| 303 | $\frac{3}{8}$ | $\frac{3}{32}$ | $2\frac{3}{32}$ | 607 | $\frac{7}{8}$ | $\frac{3}{16}$ | $2\frac{3}{16}$ | 810 | $1\frac{1}{4}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ |
| 403 | $\frac{3}{8}$ | $\frac{1}{8}$ | $2\frac{1}{8}$ | 707 | $\frac{7}{8}$ | $\frac{7}{32}$ | $2\frac{7}{32}$ | 1010 | $1\frac{1}{4}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ |
| 204 | $\frac{1}{2}$ | $\frac{1}{16}$ | $2\frac{1}{16}$ | 807 | $\frac{7}{8}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ | 1210 | $1\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{3}{8}$ |
| 304 | $\frac{1}{2}$ | $\frac{3}{32}$ | $2\frac{3}{32}$ | 608 | 1 | $\frac{3}{16}$ | $2\frac{3}{16}$ | 811 | $1\frac{3}{8}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ |
| 404 | $\frac{1}{2}$ | $\frac{1}{8}$ | $2\frac{1}{8}$ | 708 | 1 | $\frac{7}{32}$ | $2\frac{7}{32}$ | 1011 | $1\frac{3}{8}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ |
| 305 | $\frac{5}{8}$ | $\frac{3}{32}$ | $2\frac{3}{32}$ | 808 | 1 | $\frac{1}{4}$ | $2\frac{1}{4}$ | 1211 | $1\frac{3}{8}$ | $\frac{3}{8}$ | $2\frac{3}{8}$ |
| 405 | $\frac{5}{8}$ | $\frac{1}{8}$ | $2\frac{1}{8}$ | 1008 | 1 | $\frac{5}{16}$ | $2\frac{5}{16}$ | 812 | $1\frac{1}{2}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ |
| 505 | $\frac{5}{8}$ | $\frac{3}{32}$ | $2\frac{3}{32}$ | 1208 | 1 | $\frac{3}{8}$ | $2\frac{3}{8}$ | 1012 | $1\frac{1}{2}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ |
| 605 | $\frac{5}{8}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ | 609 | $1\frac{1}{8}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ | 1212 | $1\frac{1}{2}$ | $\frac{3}{8}$ | $2\frac{3}{8}$ |
| 406 | $\frac{3}{4}$ | $\frac{1}{8}$ | $2\frac{1}{8}$ | 709 | $1\frac{1}{8}$ | $\frac{7}{32}$ | $2\frac{7}{32}$ | ... | ... | ... | ... |
| Arbor-type Cutters | | | | | | | | | | | |
| Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Dia. of Hole, H | Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Dia. of Hole, H | Cutter Number | Nom. Dia. of Cutter, D | Width of Face, W | Dia. of Hole, H |
| 617 | $2\frac{1}{8}$ | $\frac{3}{16}$ | $\frac{3}{4}$ | 1022 | $2\frac{3}{4}$ | $\frac{5}{16}$ | 1 | 1628 | $3\frac{1}{2}$ | $\frac{1}{2}$ | 1 |
| 817 | $2\frac{1}{8}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | 1222 | $2\frac{3}{4}$ | $\frac{3}{8}$ | 1 | 1828 | $3\frac{1}{2}$ | $\frac{5}{16}$ | 1 |
| 1017 | $2\frac{1}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 1422 | $2\frac{3}{4}$ | $\frac{7}{16}$ | 1 | 2028 | $3\frac{1}{2}$ | $\frac{3}{8}$ | 1 |
| 1217 | $2\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | 1622 | $2\frac{3}{4}$ | $\frac{1}{2}$ | 1 | 2428 | $3\frac{1}{2}$ | $\frac{3}{4}$ | 1 |
| 822 | $2\frac{3}{4}$ | $\frac{1}{4}$ | 1 | 1228 | $3\frac{1}{2}$ | $\frac{3}{8}$ | 1 | ... | ... | ... | ... |

All dimensions are given in inches. All cutters are high-speed steel. Cutter numbers indicate nominal key dimensions or cutter sizes.

Shank type cutters are standard with right-hand cut and straight teeth. All sizes have $\frac{1}{2}$ -inch diameter shank. Arbor type cutters have staggered teeth.

For Woodruff key and key-slot dimensions, see page 162.

Tolerances: Face with W for shank type cutters: $\frac{1}{16}$ to $\frac{7}{32}$ inch face, +0.0000, -0.0005; $\frac{5}{16}$ to $\frac{7}{32}$, -0.0002, -0.0007; $\frac{1}{4}$, -0.0003, -0.0008; $\frac{5}{16}$, -0.0004, -0.0009; $\frac{3}{8}$, -0.0005, -0.0010 inch. Face width W for arbor type cutters: $\frac{5}{16}$ inch face, -0.0002, -0.0007; $\frac{1}{4}$, -0.0003, -0.0008; $\frac{5}{16}$, -0.0004, -0.0009; $\frac{3}{8}$ and over, -0.0005, -0.0010 inch. Hole size H: +0.00075, -0.0000 inch. Diameter D for shank type cutters: $\frac{1}{4}$ through $\frac{3}{4}$ -inch diameter, +0.010, +0.015, $\frac{7}{8}$ through $1\frac{1}{8}$, +0.012, +0.017; $1\frac{1}{4}$ through $1\frac{1}{2}$, +0.015, +0.020 inch. These tolerances include an allowance for sharpening. For arbor type cutters diameter D is furnished $\frac{1}{32}$ inch larger than listed and a tolerance of ± 0.002 inch applies to the oversize diameter.

KEYS AND KEYSEATS

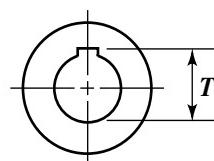
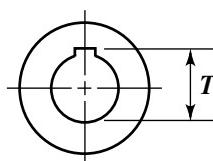
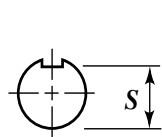
Table 1. Depth Control Values S and T for Shaft and Hub
ANSI B17.1-1967, R2003 (See figures at end of table)

| Nominal Shaft Diameter | Parallel and Taper | | Parallel | | Taper | |
|------------------------|--------------------|-------------|----------|-------------|--------|-------------|
| | Square | Rectangular | Square | Rectangular | Square | Rectangular |
| | S | S | T | T | T | T |
| $\frac{1}{2}$ | 0.430 | 0.445 | 0.560 | 0.544 | 0.535 | 0.519 |
| $\frac{5}{16}$ | 0.493 | 0.509 | 0.623 | 0.607 | 0.598 | 0.582 |
| $\frac{5}{8}$ | 0.517 | 0.548 | 0.709 | 0.678 | 0.684 | 0.653 |
| $\frac{11}{16}$ | 0.581 | 0.612 | 0.773 | 0.742 | 0.748 | 0.717 |
| $\frac{3}{4}$ | 0.644 | 0.676 | 0.837 | 0.806 | 0.812 | 0.781 |
| $\frac{13}{16}$ | 0.708 | 0.739 | 0.900 | 0.869 | 0.875 | 0.844 |
| $\frac{7}{8}$ | 0.771 | 0.802 | 0.964 | 0.932 | 0.939 | 0.907 |
| $\frac{15}{16}$ | 0.796 | 0.827 | 1.051 | 1.019 | 1.026 | 0.994 |
| 1 | 0.859 | 0.890 | 1.114 | 1.083 | 1.089 | 1.058 |
| $1\frac{1}{16}$ | 0.923 | 0.954 | 1.178 | 1.146 | 1.153 | 1.121 |
| $1\frac{1}{8}$ | 0.986 | 1.017 | 1.241 | 1.210 | 1.216 | 1.185 |
| $1\frac{3}{16}$ | 1.049 | 1.080 | 1.304 | 1.273 | 1.279 | 1.248 |
| $1\frac{1}{4}$ | 1.112 | 1.144 | 1.367 | 1.336 | 1.342 | 1.311 |
| $1\frac{5}{16}$ | 1.137 | 1.169 | 1.455 | 1.424 | 1.430 | 1.399 |
| $1\frac{3}{8}$ | 1.201 | 1.232 | 1.518 | 1.487 | 1.493 | 1.462 |
| $1\frac{7}{16}$ | 1.225 | 1.288 | 1.605 | 1.543 | 1.580 | 1.518 |
| $1\frac{1}{2}$ | 1.289 | 1.351 | 1.669 | 1.606 | 1.644 | 1.581 |
| $1\frac{9}{16}$ | 1.352 | 1.415 | 1.732 | 1.670 | 1.707 | 1.645 |
| $1\frac{5}{8}$ | 1.416 | 1.478 | 1.796 | 1.733 | 1.771 | 1.708 |
| $1\frac{11}{16}$ | 1.479 | 1.541 | 1.859 | 1.796 | 1.834 | 1.771 |
| $1\frac{3}{4}$ | 1.542 | 1.605 | 1.922 | 1.860 | 1.897 | 1.835 |
| $1\frac{13}{16}$ | 1.527 | 1.590 | 2.032 | 1.970 | 2.007 | 1.945 |
| $1\frac{7}{8}$ | 1.591 | 1.654 | 2.096 | 2.034 | 2.071 | 2.009 |
| $1\frac{15}{16}$ | 1.655 | 1.717 | 2.160 | 2.097 | 2.135 | 2.072 |
| 2 | 1.718 | 1.781 | 2.223 | 2.161 | 2.198 | 2.136 |
| $2\frac{1}{16}$ | 1.782 | 1.844 | 2.287 | 2.224 | 2.262 | 2.199 |
| $2\frac{1}{8}$ | 1.845 | 1.908 | 2.350 | 2.288 | 2.325 | 2.263 |
| $2\frac{3}{16}$ | 1.909 | 1.971 | 2.414 | 2.351 | 2.389 | 2.326 |
| $2\frac{1}{4}$ | 1.972 | 2.034 | 2.477 | 2.414 | 2.452 | 2.389 |
| $2\frac{5}{16}$ | 1.957 | 2.051 | 2.587 | 2.493 | 2.562 | 2.468 |
| $2\frac{3}{8}$ | 2.021 | 2.114 | 2.651 | 2.557 | 2.626 | 2.532 |
| $2\frac{7}{16}$ | 2.084 | 2.178 | 2.714 | 2.621 | 2.689 | 2.596 |
| $2\frac{1}{2}$ | 2.148 | 2.242 | 2.778 | 2.684 | 2.753 | 2.659 |
| $2\frac{9}{16}$ | 2.211 | 2.305 | 2.841 | 2.748 | 2.816 | 2.723 |
| $2\frac{5}{8}$ | 2.275 | 2.369 | 2.905 | 2.811 | 2.880 | 2.786 |
| $2\frac{11}{16}$ | 2.338 | 2.432 | 2.968 | 2.874 | 2.943 | 2.849 |
| $2\frac{3}{4}$ | 2.402 | 2.495 | 3.032 | 2.938 | 3.007 | 2.913 |
| $2\frac{13}{16}$ | 2.387 | 2.512 | 3.142 | 3.017 | 3.117 | 2.992 |
| $2\frac{7}{8}$ | 2.450 | 2.575 | 3.205 | 3.080 | 3.180 | 3.055 |
| $2\frac{15}{16}$ | 2.514 | 2.639 | 3.269 | 3.144 | 3.244 | 3.119 |
| 3 | 2.577 | 2.702 | 3.332 | 3.207 | 3.307 | 3.182 |
| $3\frac{1}{16}$ | 2.641 | 2.766 | 3.396 | 3.271 | 3.371 | 3.246 |
| $3\frac{1}{8}$ | 2.704 | 2.829 | 3.459 | 3.334 | 3.434 | 3.309 |
| $3\frac{3}{16}$ | 2.768 | 2.893 | 3.523 | 3.398 | 3.498 | 3.373 |
| $3\frac{1}{4}$ | 2.831 | 2.956 | 3.586 | 3.461 | 3.561 | 3.436 |
| $3\frac{5}{16}$ | 2.816 | 2.941 | 3.696 | 3.571 | 3.671 | 3.546 |

**Table 1. (Continued) Depth Control Values S and T for Shaft and Hub
ANSI B17.1-1967, R2003 (See figures at end of table)**

| Nominal Shaft Diameter | Parallel and Taper | | Parallel | | Taper | |
|------------------------|--------------------|--------------------|----------|--------------------|--------|--------------------|
| | Square | Rectangular | Square | Rectangular | Square | Rectangular |
| | S | S | T | T | T | T |
| 3 $\frac{3}{8}$ | 2.880 | 3.005 | 3.760 | 3.635 | 3.735 | 3.610 |
| 3 $\frac{7}{16}$ | 2.943 | 3.068 | 3.823 | 3.698 | 3.798 | 3.673 |
| 3 $\frac{1}{2}$ | 3.007 | 3.132 | 3.887 | 3.762 | 3.862 | 3.737 |
| 3 $\frac{9}{16}$ | 3.070 | 3.195 | 3.950 | 3.825 | 3.925 | 3.800 |
| 3 $\frac{5}{8}$ | 3.134 | 3.259 | 4.014 | 3.889 | 3.989 | 3.864 |
| 3 $\frac{11}{16}$ | 3.197 | 3.322 | 4.077 | 3.952 | 4.052 | 3.927 |
| 3 $\frac{3}{4}$ | 3.261 | 3.386 | 4.141 | 4.016 | 4.116 | 3.991 |
| 3 $\frac{13}{16}$ | 3.246 | 3.371 | 4.251 | 4.126 | 4.226 | 4.101 |
| 3 $\frac{7}{8}$ | 3.309 | 3.434 | 4.314 | 4.189 | 4.289 | 4.164 |
| 3 $\frac{15}{16}$ | 3.373 | 3.498 | 4.378 | 4.253 | 4.353 | 4.228 |
| 4 | 3.436 | 3.561 | 4.441 | 4.316 | 4.416 | 4.291 |
| 4 $\frac{3}{16}$ | 3.627 | 3.752 | 4.632 | 4.507 | 4.607 | 4.482 |
| 4 $\frac{1}{4}$ | 3.690 | 3.815 | 4.695 | 4.570 | 4.670 | 4.545 |
| 4 $\frac{3}{8}$ | 3.817 | 3.942 | 4.822 | 4.697 | 4.797 | 4.672 |
| 4 $\frac{7}{16}$ | 3.880 | 4.005 | 4.885 | 4.760 | 4.860 | 4.735 |
| 4 $\frac{1}{2}$ | 3.944 | 4.069 | 4.949 | 4.824 | 4.924 | 4.799 |
| 4 $\frac{3}{4}$ | 4.041 | 4.229 | 5.296 | 5.109 | 5.271 | 5.084 |
| 4 $\frac{7}{8}$ | 4.169 | 4.356 | 5.424 | 5.236 | 5.399 | 5.211 |
| 4 $\frac{15}{16}$ | 4.232 | 4.422 | 5.487 | 5.300 | 5.462 | 5.275 |
| 5 | 4.296 | 4.483 | 5.551 | 5.363 | 5.526 | 5.338 |
| 5 $\frac{3}{16}$ | 4.486 | 4.674 | 5.741 | 5.554 | 5.716 | 5.529 |
| 5 $\frac{1}{4}$ | 4.550 | 4.737 | 5.805 | 5.617 | 5.780 | 5.592 |
| 5 $\frac{7}{16}$ | 4.740 | 4.927 | 5.995 | 5.807 | 5.970 | 5.782 |
| 5 $\frac{1}{2}$ | 4.803 | 4.991 | 6.058 | 5.871 | 6.033 | 5.846 |
| 5 $\frac{3}{4}$ | 4.900 | 5.150 | 6.405 | 6.155 | 6.380 | 6.130 |
| 5 $\frac{15}{16}$ | 5.091 | 5.341 | 6.596 | 6.346 | 6.571 | 6.321 |
| 6 | 5.155 | 5.405 | 6.660 | 6.410 | 6.635 | 6.385 |
| 6 $\frac{1}{4}$ | 5.409 | 5.659 | 6.914 | 6.664 | 6.889 | 6.639 |
| 6 $\frac{1}{2}$ | 5.662 | 5.912 | 7.167 | 6.917 | 7.142 | 6.892 |
| 6 $\frac{3}{4}$ | 5.760 | ^a 5.885 | 7.515 | ^a 7.390 | 7.490 | ^a 7.365 |
| 7 | 6.014 | ^a 6.139 | 7.769 | ^a 7.644 | 7.744 | ^a 7.619 |
| 7 $\frac{1}{4}$ | 6.268 | ^a 6.393 | 8.023 | ^a 7.898 | 7.998 | ^a 7.873 |
| 7 $\frac{1}{2}$ | 6.521 | ^a 6.646 | 8.276 | ^a 8.151 | 8.251 | ^a 8.126 |
| 7 $\frac{3}{4}$ | 6.619 | 6.869 | 8.624 | 8.374 | 8.599 | 8.349 |
| 8 | 6.873 | 7.123 | 8.878 | 8.628 | 8.853 | 8.603 |
| 9 | 7.887 | 8.137 | 9.892 | 9.642 | 9.867 | 9.617 |
| 10 | 8.591 | 8.966 | 11.096 | 10.721 | 11.071 | 10.696 |
| 11 | 9.606 | 9.981 | 12.111 | 11.736 | 12.086 | 11.711 |
| 12 | 10.309 | 10.809 | 13.314 | 12.814 | 13.289 | 12.789 |
| 13 | 11.325 | 11.825 | 14.330 | 13.830 | 14.305 | 13.805 |
| 14 | 12.028 | 12.528 | 15.533 | 15.033 | 15.508 | 15.008 |
| 15 | 13.043 | 13.543 | 16.548 | 16.048 | 16.523 | 16.023 |

^a1 $\frac{3}{4}$ × 1 $\frac{1}{2}$ inch key.



All dimensions are given in inches. See Table 2 for tolerances.

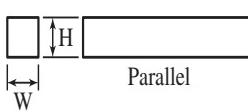
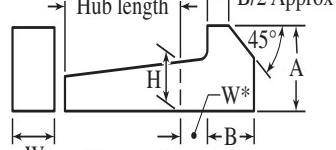
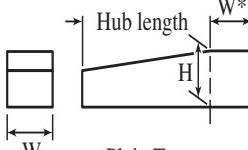
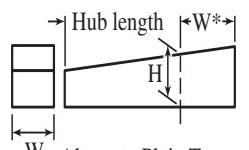
Table 2. ANSI Standard Fits for Parallel and Taper Keys ANSI B17.1-1967, R2003

| Type of Key | Key Width | | Side Fit | | | Top and Bottom Fit | | | |
|---|----------------|----------------|-----------------|----------|---------------------------|--------------------|-------------------|-----------------|---------------------------|
| | Over | To (Incl.) | Width Tolerance | | Fit Range ^a | Depth Tolerance | | Hub Key-Seat | Fit Range ^a |
| | | | Key | Key-Seat | | Key | Shaft Key-Seat | | |
| Class 1 Fit for Parallel Keys | | | | | | | | | |
| Square | ... | $\frac{1}{2}$ | +0.000 | +0.002 | 0.004 CL | +0.000 | +0.000 | +0.010 | 0.032 CL |
| | | | -0.002 | -0.000 | 0.000 | -0.002 | -0.015 | -0.000 | 0.005 CL |
| | | $\frac{3}{4}$ | +0.000 | +0.003 | 0.005 CL | +0.000 | +0.000 | +0.010 | 0.032 CL |
| | | | -0.002 | -0.000 | 0.000 | -0.002 | -0.015 | -0.000 | 0.005 CL |
| | $\frac{3}{4}$ | 1 | +0.000 | +0.003 | 0.006 CL | +0.000 | +0.000 | +0.010 | 0.033 CL |
| | | | -0.003 | -0.000 | 0.000 | -0.003 | -0.015 | -0.000 | 0.005 CL |
| | | $1\frac{1}{2}$ | +0.000 | +0.004 | 0.007 CL | +0.000 | +0.000 | +0.010 | 0.033 CL |
| | | | -0.003 | -0.000 | 0.000 | -0.003 | -0.015 | -0.000 | 0.005 CL |
| Rectan- gular | $1\frac{1}{2}$ | $2\frac{1}{2}$ | +0.000 | +0.004 | 0.008 CL | +0.000 | +0.000 | +0.010 | 0.034 CL |
| | | | -0.004 | -0.000 | 0.000 | -0.004 | -0.015 | -0.000 | 0.005 CL |
| | | $2\frac{1}{2}$ | +0.000 | +0.004 | 0.010 CL | +0.000 | +0.000 | +0.010 | 0.036 CL |
| | | | -0.006 | -0.000 | 0.000 | -0.006 | -0.015 | -0.000 | 0.005 CL |
| | 3 | $\frac{1}{2}$ | +0.000 | +0.002 | 0.005 CL | +0.000 | +0.000 | +0.010 | 0.033 CL |
| | | | -0.003 | -0.000 | 0.000 | -0.003 | -0.015 | -0.000 | 0.005 CL |
| | | $\frac{3}{4}$ | +0.000 | +0.003 | 0.006 CL | +0.000 | +0.000 | +0.010 | 0.033 CL |
| | | | -0.003 | -0.000 | 0.000 | -0.003 | -0.015 | -0.000 | 0.005 CL |
| | | 1 | +0.000 | +0.003 | 0.007 CL | +0.000 | +0.000 | +0.010 | 0.034 CL |
| | | | -0.004 | -0.000 | 0.000 | -0.004 | -0.015 | -0.000 | 0.005 CL |
| Class 2 Fit for Parallel and Taper Keys | | | | | | | | | |
| Parallel Square | $1\frac{1}{4}$ | $1\frac{1}{4}$ | +0.001 | +0.002 | 0.002 CL | +0.001 | +0.000 | +0.010 | 0.030 CL |
| | | | -0.000 | -0.000 | 0.001 INT | -0.000 | -0.015 | -0.000 | 0.004 CL |
| | | 3 | +0.002 | +0.002 | 0.002 CL | +0.002 | +0.000 | +0.010 | 0.030 CL |
| | 3 | $3\frac{1}{2}$ | -0.000 | -0.000 | 0.002 INT | -0.000 | -0.015 | -0.000 | 0.003 CL |
| | | | +0.003 | +0.002 | 0.002 CL | +0.003 | +0.000 | +0.010 | 0.030 CL |
| Parallel Rectan- gular | $1\frac{1}{4}$ | $1\frac{1}{4}$ | +0.001 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.035 CL |
| | | | -0.000 | -0.000 | 0.001 INT | -0.005 | -0.015 | -0.000 | 0.000 CL |
| | | 3 | +0.002 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.035 CL |
| | 3 | 7 | -0.000 | -0.000 | 0.002 INT | -0.005 | -0.015 | -0.000 | 0.000 CL |
| | | | +0.003 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.035 CL |
| | | 7 | -0.000 | -0.000 | 0.003 INT | -0.005 | -0.015 | -0.000 | 0.000 CL |
| Taper | $1\frac{1}{4}$ | $1\frac{1}{4}$ | +0.001 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.005 CL |
| | | | -0.000 | -0.000 | 0.001 INT | -0.000 | -0.015 | -0.000 | 0.025 INT |
| | | 3 | +0.002 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.005 CL |
| | 3 | 3 | -0.000 | -0.000 | 0.002 INT | -0.000 | -0.015 | -0.000 | 0.025 INT |
| | | | +0.003 | +0.002 | 0.002 CL | +0.005 | +0.000 | +0.010 | 0.005 CL |
| | | b | -0.000 | -0.000 | 0.003 INT | -0.000 | -0.015 | -0.000 | 0.025 INT |

^aLimits of variation. CL = Clearance; INT = Interference.^bTo (Incl.) $3\frac{1}{2}$ -inch Square and 7-inch Rectangular key widths.

All dimensions are given in inches. See also text on page 161.

Table 3. ANSI Standard Plain and Gib Head Keys ANSI B17.1-1967, R2003

| | | |  Parallel | |  Gib Head Taper | | | | |
|----------|---|-----------|--|-----------------|--|---------------|---------------|---------------|--|
| | | |  Plain Taper | |  Alternate Plain Taper | | | | |
| Key | | | Nominal Key Size | | Tolerance | | | | |
| | | | Width <i>W</i> | Over To (Incl.) | | | | | |
| | | | ... 1 1/4 | ... 1 1/4 | +0.001 -0.000 | +0.001 -0.000 | +0.001 -0.000 | +0.001 -0.000 | |
| Parallel | Square | Keystock | ... 1 1/4 | ... 1 1/4 | +0.002 -0.000 | +0.002 -0.000 | +0.002 -0.000 | +0.002 -0.000 | |
| | | | 3 | 3 | +0.003 -0.000 | +0.003 -0.000 | +0.003 -0.000 | +0.003 -0.000 | |
| | | | 3 1/2 | 3 1/2 | +0.004 -0.000 | +0.004 -0.000 | +0.004 -0.000 | +0.004 -0.000 | |
| | | Bar Stock | ... 3/4 | ... 3/4 | +0.000 -0.002 | +0.000 -0.002 | +0.000 -0.002 | +0.000 -0.002 | |
| | | | 3/4 | 1 1/2 | +0.000 -0.003 | +0.000 -0.003 | +0.000 -0.003 | +0.000 -0.003 | |
| | | | 1 1/2 | 2 1/2 | +0.000 -0.004 | +0.000 -0.004 | +0.000 -0.004 | +0.000 -0.004 | |
| | Rectangular | Keystock | 2 1/2 | 3 1/2 | +0.000 -0.006 | +0.000 -0.006 | +0.000 -0.006 | +0.000 -0.006 | |
| | | | 3 | 4 | +0.000 -0.008 | +0.000 -0.008 | +0.000 -0.008 | +0.000 -0.008 | |
| | | | 4 | 6 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | |
| | | Bar Stock | 6 | 7 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | |
| | | | 7 | 8 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | |
| | | | 8 | 9 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | +0.000 -0.013 | |
| Taper | Plain or Gib Head Square or Rectangular | | ... 1 1/4 | ... 1 1/4 | +0.001 -0.000 | +0.001 -0.000 | +0.001 -0.000 | +0.001 -0.000 | |
| | | | 1 1/4 | 3 | +0.002 -0.000 | +0.002 -0.000 | +0.002 -0.000 | +0.002 -0.000 | |
| | | | 3 | 7 | +0.003 -0.000 | +0.003 -0.000 | +0.003 -0.000 | +0.003 -0.000 | |

Gib Head Nominal Dimensions

| Nominal Key Size Width, <i>W</i> | Square | | | Rectangular | | | Nominal Key Size Width, <i>W</i> | Square | | | Rectangular | | |
|----------------------------------|----------|----------|----------|-------------|----------|----------|----------------------------------|----------|----------|----------|-------------|----------|----------|
| | <i>H</i> | <i>A</i> | <i>B</i> | <i>H</i> | <i>A</i> | <i>B</i> | | <i>H</i> | <i>A</i> | <i>B</i> | <i>H</i> | <i>A</i> | <i>B</i> |
| 1/8 | 1/8 | 1/4 | 1/4 | 3/32 | 3/16 | 1/8 | 1 | 1 | 1 5/8 | 1 1/8 | 3/4 | 1 1/4 | 7/8 |
| 3/16 | 3/16 | 5/16 | 5/16 | 1/8 | 1/4 | 1/4 | 1 1/4 | 1 1/4 | 2 | 1 7/16 | 7/8 | 1 3/8 | 1 |
| 1/4 | 1/4 | 7/16 | 3/8 | 3/16 | 5/16 | 5/16 | 1 1/2 | 1 1/2 | 2 3/8 | 1 3/4 | 1 | 1 5/8 | 1 1/8 |
| 5/16 | 5/16 | 1/2 | 7/16 | 1/4 | 7/16 | 3/8 | 1 3/4 | 1 3/4 | 2 3/4 | 2 | 1 1/2 | 2 3/8 | 1 3/4 |
| 3/8 | 3/8 | 5/8 | 1/2 | 1/4 | 7/16 | 3/8 | 2 | 2 | 3 1/2 | 2 1/4 | 1 1/2 | 2 3/8 | 1 3/4 |
| 1/2 | 1/2 | 7/8 | 5/8 | 3/8 | 5/8 | 1/2 | 2 1/2 | 2 1/2 | 4 | 3 | 1 3/4 | 2 3/4 | 2 |
| 5/8 | 5/8 | 1 | 3/4 | 7/16 | 3/4 | 7/16 | 3 | 3 | 5 | 3 1/2 | 2 | 3 1/2 | 2 5/8 |
| 3/4 | 3/4 | 1 1/4 | 7/8 | 1/2 | 7/8 | 5/8 | 3 1/2 | 3 1/2 | 6 | 4 | 2 1/2 | 4 | 3 |
| 7/8 | 7/8 | 1 3/8 | 1 | 5/8 | 1 | 3/4 | ... | ... | ... | ... | ... | ... | ... |

All dimensions are given in inches.

*For locating position of dimension *H*. Tolerance does not apply.For larger sizes the following relationships are suggested as guides for establishing *A* and *B*: *A* = 1.8*H* and *B* = 1.2*H*.

Table 4. Finding Depth of Keyseat and Distance from Top of Key to Bottom of Shaft

For milling keyseats, the total depth to feed cutter in from outside of shaft to bottom of keyseat is $M + D$, where D is depth of keyseat.

For checking an assembled key and shaft, caliper measurement J between top of key and bottom of shaft is used.

$$J = S - (M + D) + C$$

where C is depth of key. For Woodruff keys, dimensions C and D can be found in Table 5. Assuming shaft diameter S is normal size, the tolerance on dimension J for Woodruff keys in keyslots are $+0.000, -0.010$ inch.

| Dia. of Shaft S . Inches | Width of Keyseat, E | | | | | | | | | | | | | |
|-------------------------------------|-----------------------|----------------|---------------|----------------|----------------|----------------|---------------|----------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
| | $\frac{1}{16}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{5}{32}$ | $\frac{3}{16}$ | $\frac{7}{32}$ | $\frac{1}{4}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{13}{16}$ | $\frac{7}{8}$ | $\frac{15}{16}$ |
| | Dimension M , Inch | | | | | | | | | | | | | |
| 0.3125 | .0032 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.3437 | .0029 | .0065 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.3750 | .0026 | .0060 | .0107 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.4060 | .0024 | .0055 | .0099 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.4375 | .0022 | .0051 | .0091 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.4687 | .0021 | .0047 | .0085 | .0134 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.5000 | .0020 | .0044 | .0079 | .0125 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.5625 | ... | .0039 | .0070 | .0111 | .0161 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.6250 | ... | .0035 | .0063 | .0099 | .0144 | .0198 | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.6875 | ... | .0032 | .0057 | .0090 | .0130 | .0179 | .0235 | ... | ... | ... | ... | ... | ... | ... |
| 0.7500 | ... | .0029 | .0052 | .0082 | .0119 | .0163 | .0214 | .0341 | ... | ... | ... | ... | ... | ... |
| 0.8125 | ... | .0027 | .0048 | .0076 | .0110 | .0150 | .0197 | .0312 | ... | ... | ... | ... | ... | ... |
| 0.8750 | ... | .0025 | .0045 | .0070 | .0102 | .0139 | .0182 | .0288 | ... | ... | ... | ... | ... | ... |
| 0.9375 | ... | ... | .0042 | .0066 | .0095 | .0129 | .0170 | .0263 | .0391 | ... | ... | ... | ... | ... |
| 1.0000 | ... | ... | .0039 | .0061 | .0089 | .0121 | .0159 | .0250 | .0365 | ... | ... | ... | ... | ... |
| 1.0625 | ... | ... | .0037 | .0058 | .0083 | .0114 | .0149 | .0235 | .0342 | ... | ... | ... | ... | ... |
| 1.1250 | ... | ... | .0035 | .0055 | .0079 | .0107 | .0141 | .0221 | .0322 | .0443 | ... | ... | ... | ... |
| 1.1875 | ... | ... | .0033 | .0052 | .0074 | .0102 | .0133 | .0209 | .0304 | .0418 | ... | ... | ... | ... |
| 1.2500 | ... | ... | .0031 | .0049 | .0071 | .0097 | .0126 | .0198 | .0288 | .0395 | ... | ... | ... | ... |
| 1.3750 | ... | ... | ... | .0045 | .0064 | .0088 | .0115 | .0180 | .0261 | .0357 | .0471 | ... | ... | ... |
| 1.5000 | ... | ... | ... | .0041 | .0059 | .0080 | .0105 | .0165 | .0238 | .0326 | .0429 | ... | ... | ... |
| 1.6250 | ... | ... | ... | .0038 | .0054 | .0074 | .0097 | .0152 | .0219 | .0300 | .0394 | .0502 | ... | ... |
| 1.7500 | ... | ... | ... | ... | .0050 | .0069 | .0090 | .0141 | .0203 | .0278 | .0365 | .0464 | ... | ... |
| 1.8750 | ... | ... | ... | ... | .0047 | .0064 | .0084 | .0131 | .0189 | .0259 | .0340 | .0432 | .0536 | ... |
| 2.0000 | ... | ... | ... | ... | .0044 | .0060 | .0078 | .0123 | .0177 | .0242 | .0318 | .0404 | .0501 | ... |
| 2.1250 | ... | ... | ... | ... | ... | .0056 | .0074 | .0116 | .0167 | .0228 | .0298 | .0379 | .0470 | .0572 |
| 2.2500 | ... | ... | ... | ... | ... | ... | .0070 | .0109 | .0157 | .0215 | .0281 | .0357 | .0443 | .0538 |
| 2.3750 | ... | ... | ... | ... | ... | ... | ... | .0103 | .0149 | .0203 | .0266 | .0338 | .0419 | .0509 |
| 2.5000 | ... | ... | ... | ... | ... | ... | ... | ... | .0141 | .0193 | .0253 | .0321 | .0397 | .0482 |
| 2.6250 | ... | ... | ... | ... | ... | ... | ... | ... | .0135 | .0184 | .0240 | .0305 | .0377 | .0457 |
| 2.7500 | ... | ... | ... | ... | ... | ... | ... | ... | ... | .0175 | .0229 | .0291 | .0360 | .0437 |
| 2.8750 | ... | ... | ... | ... | ... | ... | ... | ... | ... | .0168 | .0219 | .0278 | .0344 | .0417 |
| 3.0000 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | .0210 | .0266 | .0329 | .0399 |
| | | | | | | | | | | | | | | .0476 |

ANSI Standard Woodruff Keys and Keyseats.—American National Standard B17.2 was approved in 1967, and reaffirmed in 1990. Data from this standard are shown in Tables below. The following definitions are given in this standard:

Woodruff Key: A Remountable machinery part which, when assembled into key-seats, provides a positive means for transmitting torque between the shaft and hub.

Woodruff Key Number: An identification number by which the size of key may be readily determined.

Woodruff Keyseat—Shaft: The circular pocket in which the key is retained.

Woodruff Keyseat—Hub: An axially located rectangular groove in a hub. (This has been referred to as a keyway.)

Woodruff Keyseat Milling Cutter: An arbor type or shank type milling cutter normally used for milling Woodruff keyseats in shafts.

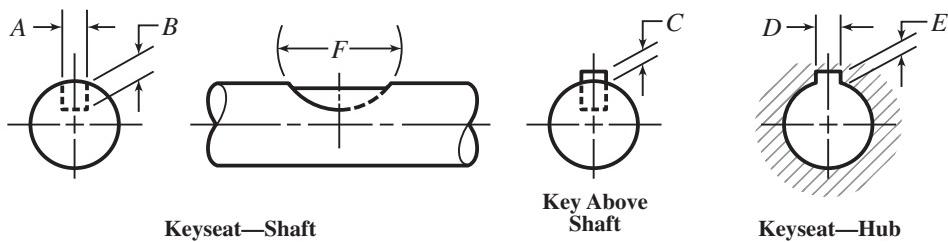


Table 5. ANSI Keyseat Dimensions for Woodruff Keys

ANSI B17.2-1967, R2003

| Key No. | Nominal Size Key | Keyseat—Shaft | | | | | Key Above Shaft | Keyseat—Hub | |
|---------|------------------------------------|----------------------|--------|------------------|------------|-------|------------------|------------------|------------------|
| | | Width A ^a | | Depth B | Diameter F | | | Width D | Depth E |
| | | Min. | Max. | +0.005 -0.000 | Min. | Max. | +0.005 -0.005 | +0.002 -0.000 | +0.005 -0.000 |
| 202 | $\frac{1}{16} \times \frac{1}{4}$ | 0.0615 | 0.0630 | 0.0728 | 0.250 | 0.268 | 0.0312 | 0.0635 | 0.0372 |
| 202.5 | $\frac{1}{16} \times \frac{5}{16}$ | 0.0615 | 0.0630 | 0.1038 | 0.312 | 0.330 | 0.0312 | 0.0635 | 0.0372 |
| 302.5 | $\frac{3}{32} \times \frac{5}{16}$ | 0.0928 | 0.0943 | 0.0882 | 0.312 | 0.330 | 0.0469 | 0.0948 | 0.0529 |
| 203 | $\frac{1}{16} \times \frac{3}{8}$ | 0.0615 | 0.0630 | 0.1358 | 0.375 | 0.393 | 0.0312 | 0.0635 | 0.0372 |
| 303 | $\frac{3}{32} \times \frac{3}{8}$ | 0.0928 | 0.0943 | 0.1202 | 0.375 | 0.393 | 0.0469 | 0.0948 | 0.0529 |
| 403 | $\frac{1}{8} \times \frac{3}{8}$ | 0.1240 | 0.1255 | 0.1045 | 0.375 | 0.393 | 0.0625 | 0.1260 | 0.0685 |
| 204 | $\frac{1}{16} \times \frac{1}{2}$ | 0.0615 | 0.0630 | 0.1668 | 0.500 | 0.518 | 0.0312 | 0.0635 | 0.0372 |
| 304 | $\frac{3}{32} \times \frac{1}{2}$ | 0.0928 | 0.0943 | 0.1511 | 0.500 | 0.518 | 0.0469 | 0.0948 | 0.0529 |
| 404 | $\frac{1}{8} \times \frac{1}{2}$ | 0.1240 | 0.1255 | 0.1355 | 0.500 | 0.518 | 0.0625 | 0.1260 | 0.0685 |
| 305 | $\frac{3}{32} \times \frac{5}{8}$ | 0.0928 | 0.0943 | 0.1981 | 0.625 | 0.643 | 0.0469 | 0.0948 | 0.0529 |
| 405 | $\frac{1}{8} \times \frac{5}{8}$ | 0.1240 | 0.1255 | 0.1825 | 0.625 | 0.643 | 0.0625 | 0.1260 | 0.0685 |
| 505 | $\frac{5}{32} \times \frac{5}{8}$ | 0.1553 | 0.1568 | 0.1669 | 0.625 | 0.643 | 0.0781 | 0.1573 | 0.0841 |
| 605 | $\frac{3}{16} \times \frac{5}{8}$ | 0.1863 | 0.1880 | 0.1513 | 0.625 | 0.643 | 0.0937 | 0.1885 | 0.0997 |
| 406 | $\frac{1}{8} \times \frac{3}{4}$ | 0.1240 | 0.1255 | 0.2455 | 0.750 | 0.768 | 0.0625 | 0.1260 | 0.0685 |
| 506 | $\frac{5}{32} \times \frac{3}{4}$ | 0.1553 | 0.1568 | 0.2299 | 0.750 | 0.768 | 0.0781 | 0.1573 | 0.0841 |
| 606 | $\frac{3}{16} \times \frac{3}{4}$ | 0.1863 | 0.1880 | 0.2143 | 0.750 | 0.768 | 0.0937 | 0.1885 | 0.0997 |
| 806 | $\frac{1}{4} \times \frac{3}{4}$ | 0.2487 | 0.2505 | 0.1830 | 0.750 | 0.768 | 0.1250 | 0.2510 | 0.1310 |
| 507 | $\frac{5}{32} \times \frac{7}{8}$ | 0.1553 | 0.1568 | 0.2919 | 0.875 | 0.895 | 0.0781 | 0.1573 | 0.0841 |
| 607 | $\frac{3}{16} \times \frac{7}{8}$ | 0.1863 | 0.1880 | 0.2763 | 0.875 | 0.895 | 0.0937 | 0.1885 | 0.0997 |
| 707 | $\frac{7}{32} \times \frac{7}{8}$ | 0.2175 | 0.2193 | 0.2607 | 0.875 | 0.895 | 0.1093 | 0.2198 | 0.1153 |
| 807 | $\frac{1}{4} \times \frac{7}{8}$ | 0.2487 | 0.2505 | 0.2450 | 0.875 | 0.895 | 0.1250 | 0.2510 | 0.1310 |
| 608 | $\frac{3}{16} \times 1$ | 0.1863 | 0.1880 | 0.3393 | 1.000 | 1.020 | 0.0937 | 0.1885 | 0.0997 |
| 708 | $\frac{7}{32} \times 1$ | 0.2175 | 0.2193 | 0.3237 | 1.000 | 1.020 | 0.1093 | 0.2198 | 0.1153 |
| 808 | $\frac{1}{4} \times 1$ | 0.2487 | 0.2505 | 0.3080 | 1.000 | 1.020 | 0.1250 | 0.2510 | 0.1310 |
| 1008 | $\frac{5}{16} \times 1$ | 0.3111 | 0.3130 | 0.2768 | 1.000 | 1.020 | 0.1562 | 0.3135 | 0.1622 |
| 1208 | $\frac{3}{8} \times 1$ | 0.3735 | 0.3755 | 0.2455 | 1.000 | 1.020 | 0.1875 | 0.3760 | 0.1935 |
| 609 | $\frac{5}{16} \times 1\frac{1}{8}$ | 0.1863 | 0.1880 | 0.3853 | 1.125 | 1.145 | 0.0937 | 0.1885 | 0.0997 |
| 709 | $\frac{7}{32} \times 1\frac{1}{8}$ | 0.2175 | 0.2193 | 0.3697 | 1.125 | 1.145 | 0.1093 | 0.2198 | 0.1153 |
| 809 | $\frac{1}{4} \times 1\frac{1}{8}$ | 0.2487 | 0.2505 | 0.3540 | 1.125 | 1.145 | 0.1250 | 0.2510 | 0.1310 |
| 1009 | $\frac{5}{16} \times 1\frac{1}{8}$ | 0.3111 | 0.3130 | 0.3228 | 1.125 | 1.145 | 0.1562 | 0.3135 | 0.1622 |
| 610 | $\frac{5}{16} \times 1\frac{1}{4}$ | 0.1863 | 0.1880 | 0.4483 | 1.250 | 1.273 | 0.0937 | 0.1885 | 0.0997 |
| 710 | $\frac{7}{32} \times 1\frac{1}{4}$ | 0.2175 | 0.2193 | 0.4327 | 1.250 | 1.273 | 0.1093 | 0.2198 | 0.1153 |

**Table 5. (Continued) ANSI Keyseat Dimensions for Woodruff Keys
ANSI B17.2-1967, R2003**

| Key No. | Nominal Size Key | Keyseat—Shaft | | | | | Key Above Shaft | Keyseat—Hub | |
|---------|-------------------------------------|----------------------|--------|------------------|------------|-------|------------------|------------------|------------------|
| | | Width A ^a | | Depth B | Diameter F | | | Width D | Depth E |
| | | Min. | Max. | +0.005 -0.000 | Min. | Max. | +0.005 -0.005 | +0.002 -0.000 | +0.005 -0.000 |
| 810 | $\frac{1}{4} \times 1\frac{1}{4}$ | 0.2487 | 0.2505 | 0.4170 | 1.250 | 1.273 | 0.1250 | 0.2510 | 0.1310 |
| 1010 | $\frac{5}{16} \times 1\frac{1}{4}$ | 0.3111 | 0.3130 | 0.3858 | 1.250 | 1.273 | 0.1562 | 0.3135 | 0.1622 |
| 1210 | $\frac{3}{8} \times 1\frac{1}{4}$ | 0.3735 | 0.3755 | 0.3545 | 1.250 | 1.273 | 0.1875 | 0.3760 | 0.1935 |
| 811 | $\frac{1}{4} \times 1\frac{3}{8}$ | 0.2487 | 0.2505 | 0.4640 | 1.375 | 1.398 | 0.1250 | 0.2510 | 0.1310 |
| 1011 | $\frac{5}{16} \times 1\frac{3}{8}$ | 0.3111 | 0.3130 | 0.4328 | 1.375 | 1.398 | 0.1562 | 0.3135 | 0.1622 |
| 1211 | $\frac{3}{8} \times 1\frac{3}{8}$ | 0.3735 | 0.3755 | 0.4015 | 1.375 | 1.398 | 0.1875 | 0.3760 | 0.1935 |
| 812 | $\frac{1}{4} \times 1\frac{1}{2}$ | 0.2487 | 0.2505 | 0.5110 | 1.500 | 1.523 | 0.1250 | 0.2510 | 0.1310 |
| 1012 | $\frac{5}{16} \times 1\frac{1}{2}$ | 0.3111 | 0.3130 | 0.4798 | 1.500 | 1.523 | 0.1562 | 0.3135 | 0.1622 |
| 1212 | $\frac{3}{8} \times 1\frac{1}{2}$ | 0.3735 | 0.3755 | 0.4485 | 1.500 | 1.523 | 0.1875 | 0.3760 | 0.1935 |
| 617-1 | $\frac{3}{16} \times 2\frac{1}{8}$ | 0.1863 | 0.1880 | 0.3073 | 2.125 | 2.160 | 0.0937 | 0.1885 | 0.0997 |
| 817-1 | $\frac{1}{4} \times 2\frac{1}{8}$ | 0.2487 | 0.2505 | 0.2760 | 2.125 | 2.160 | 0.1250 | 0.2510 | 0.1310 |
| 1017-1 | $\frac{5}{16} \times 2\frac{1}{8}$ | 0.3111 | 0.3130 | 0.2448 | 2.125 | 2.160 | 0.1562 | 0.3135 | 0.1622 |
| 1217-1 | $\frac{3}{8} \times 2\frac{1}{8}$ | 0.3735 | 0.3755 | 0.2135 | 2.125 | 2.160 | 0.1875 | 0.3760 | 0.1935 |
| 617 | $\frac{3}{16} \times 2\frac{1}{8}$ | 0.1863 | 0.1880 | 0.4323 | 2.125 | 2.160 | 0.0937 | 0.1885 | 0.0997 |
| 817 | $\frac{1}{4} \times 2\frac{1}{8}$ | 0.2487 | 0.2505 | 0.4010 | 2.125 | 2.160 | 0.1250 | 0.2510 | 0.1310 |
| 1017 | $\frac{5}{16} \times 2\frac{1}{8}$ | 0.3111 | 0.3130 | 0.3698 | 2.125 | 2.160 | 0.1562 | 0.3135 | 0.1622 |
| 1217 | $\frac{3}{8} \times 2\frac{1}{8}$ | 0.3735 | 0.3755 | 0.3385 | 2.125 | 2.160 | 0.1875 | 0.3760 | 0.1935 |
| 822-1 | $\frac{1}{4} \times 2\frac{3}{4}$ | 0.2487 | 0.2505 | 0.4640 | 2.750 | 2.785 | 0.1250 | 0.2510 | 0.1310 |
| 1022-1 | $\frac{5}{16} \times 2\frac{3}{4}$ | 0.3111 | 0.3130 | 0.4328 | 2.750 | 2.785 | 0.1562 | 0.3135 | 0.1622 |
| 1222-1 | $\frac{3}{8} \times 2\frac{3}{4}$ | 0.3735 | 0.3755 | 0.4015 | 2.750 | 2.785 | 0.1875 | 0.3760 | 0.1935 |
| 1422-1 | $\frac{7}{16} \times 2\frac{3}{4}$ | 0.4360 | 0.4380 | 0.3703 | 2.750 | 2.785 | 0.2187 | 0.4385 | 0.2247 |
| 1622-1 | $\frac{1}{2} \times 2\frac{3}{4}$ | 0.4985 | 0.5005 | 0.3390 | 2.750 | 2.785 | 0.2500 | 0.5010 | 0.2560 |
| 822 | $\frac{1}{4} \times 2\frac{3}{4}$ | 0.2487 | 0.2505 | 0.6200 | 2.750 | 2.785 | 0.1250 | 0.2510 | 0.1310 |
| 1022 | $\frac{5}{16} \times 2\frac{3}{4}$ | 0.3111 | 0.3130 | 0.5888 | 2.750 | 2.785 | 0.1562 | 0.3135 | 0.1622 |
| 1222 | $\frac{3}{8} \times 2\frac{3}{4}$ | 0.3735 | 0.3755 | 0.5575 | 2.750 | 2.785 | 0.1875 | 0.3760 | 0.1935 |
| 1422 | $\frac{7}{16} \times 2\frac{3}{4}$ | 0.4360 | 0.4380 | 0.5263 | 2.750 | 2.785 | 0.2187 | 0.4385 | 0.2247 |
| 1622 | $\frac{1}{2} \times 2\frac{3}{4}$ | 0.4985 | 0.5005 | 0.4950 | 2.750 | 2.785 | 0.2500 | 0.5010 | 0.2560 |
| 1228 | $\frac{3}{8} \times 3\frac{1}{2}$ | 0.3735 | 0.3755 | 0.7455 | 3.500 | 3.535 | 0.1875 | 0.3760 | 0.1935 |
| 1428 | $\frac{7}{16} \times 3\frac{1}{2}$ | 0.4360 | 0.4380 | 0.7143 | 3.500 | 3.535 | 0.2187 | 0.4385 | 0.2247 |
| 1628 | $\frac{1}{2} \times 3\frac{1}{2}$ | 0.4985 | 0.5005 | 0.6830 | 3.500 | 3.535 | 0.2500 | 0.5010 | 0.2560 |
| 1828 | $\frac{9}{16} \times 3\frac{1}{2}$ | 0.5610 | 0.5630 | 0.6518 | 3.500 | 3.535 | 0.2812 | 0.5635 | 0.2872 |
| 2028 | $\frac{5}{8} \times 3\frac{1}{2}$ | 0.6235 | 0.6255 | 0.6205 | 3.500 | 3.535 | 0.3125 | 0.6260 | 0.3185 |
| 2228 | $\frac{11}{16} \times 3\frac{1}{2}$ | 0.6860 | 0.6880 | 0.5893 | 3.500 | 3.535 | 0.3437 | 0.6885 | 0.3497 |
| 2428 | $\frac{3}{4} \times 3\frac{1}{2}$ | 0.7485 | 0.7505 | 0.5580 | 3.500 | 3.535 | 0.3750 | 0.7510 | 0.3810 |

^a These Width A values were set with the maximum keyseat (shaft) width as that figure which will receive a key with the greatest amount of looseness consistent with assuring the key's sticking in the keyseat (shaft). Minimum keyseat width is that figure permitting the largest shaft distortion acceptable when assembling maximum key in minimum keyseat. Dimensions A, B, C, D are taken at side intersection.

All dimensions are given in inches.

BROACHING

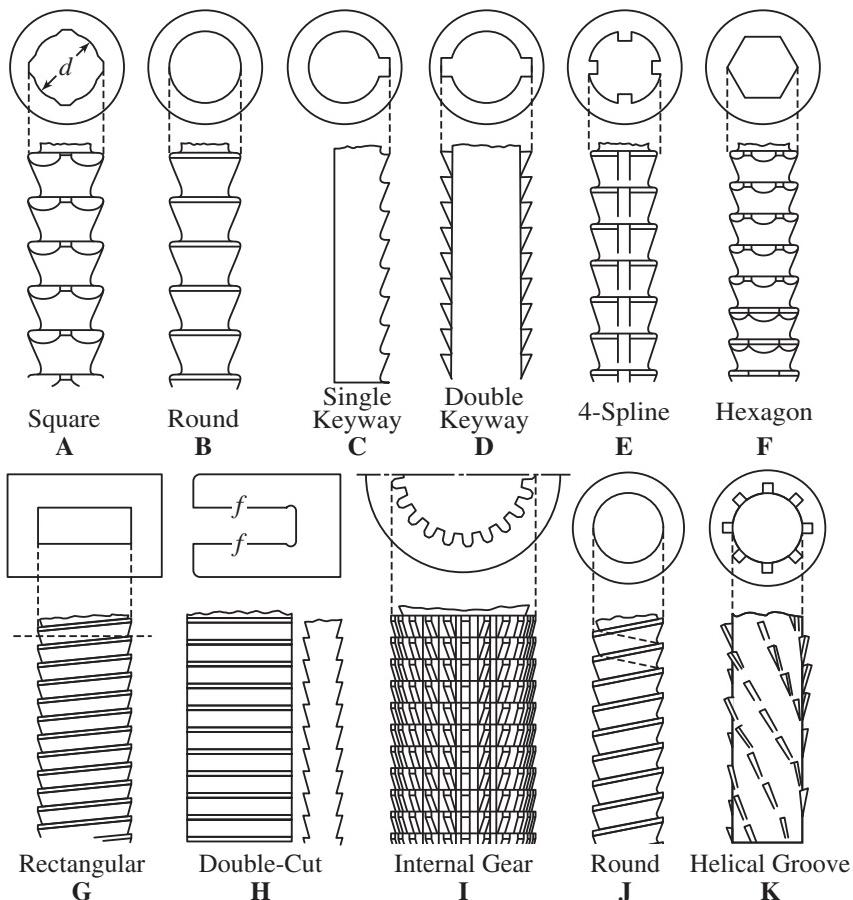
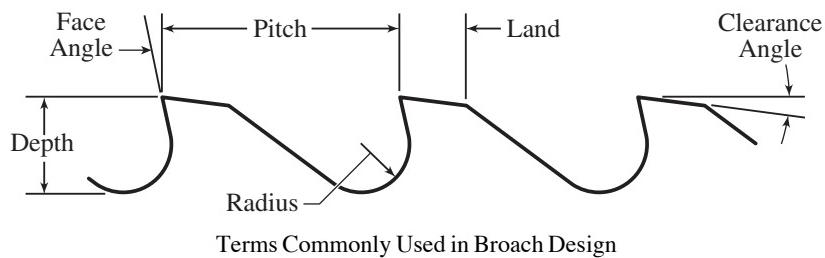


Fig. 1. Types of Broaches

Pitch of Broach Teeth.— The pitch of broach teeth depends upon the depth of cut or chip thickness, length of cut, the cutting force required and power of the broaching machine. In the pitch formulas which follow

L = length, in inches, of layer to be removed by broaching

d = depth of cut per tooth as shown by Table 1 (For internal broaches, d = depth of cut as measured on one side of broach or one-half difference in diameters of successive teeth in case of a round broach)

F = a factor. (For brittle types of material, F = 3 or 4 for roughing teeth, and 6 for finishing teeth. For ductile types of material, F = 4 to 7 for roughing teeth and 8 for finishing teeth.)

b = width of inches, of layer to be removed by broaching

P = pressure required in tons per square inch, of an area equal to depth of cut times width of cut, in inches (Table 2)

T = usable capacity, in tons, of broaching machine = 70 per cent of maximum tonnage

Table 1. Designing Data for Surface Broaches

| Material to be Broached | Depth of Cut per Tooth, Inch | | Face Angle or Rake, Degrees | Clearance Angle, Degrees | |
|--------------------------------|------------------------------|-----------|-----------------------------|--------------------------|-----------|
| | Roughing ^a | Finishing | | Roughing | Finishing |
| Steel, High Tensile Strength | 0.0015–0.002 | 0.0005 | 10–12 | 1.5–3 | 0.5–1 |
| Steel, Medium Tensile Strength | 0.0025–0.005 | 0.0005 | 14–18 | 1.5–3 | 0.5–1 |
| Cast Steel | 0.0025–0.005 | 0.0005 | 10 | 1.53 | 0.5 |
| Malleable Iron | 0.0025–0.005 | 0.0005 | 7 | 1.5–3 | 0.5 |
| Cast Iron, Soft | 0.006–0.010 | 0.0005 | 10–15 | 1.5–3 | 0.5 |
| Cast Iron, Hard | 0.003–0.005 | 0.0005 | 5 | 1.5–3 | 0.5 |
| Zinc Die Castings | 0.005–0.010 | 0.0010 | 12 ^b | 5 | 2 |
| Cast Bronze | 0.010–0.025 | 0.0005 | 8 | 0 | 0 |
| Wrought Aluminum Alloys | 0.005–0.010 | 0.0010 | 15 ^b | 3 | 1 |
| Cast Aluminum Alloys | 0.005–0.010 | 0.0010 | 12 ^b | 3 | 1 |
| Magnesium Die Castings | 0.010–0.015 | 0.0010 | 20 ^b | 3 | 1 |

^aThe lower depth-of-cut values for roughing are recommended when work is not very rigid, the tolerance is small, a good finish is required, or length of cut is comparatively short.

^bIn broaching these materials, smooth surfaces for tooth and chip spaces are especially recommended.

Table 2. Broaching Pressure P for Use in Pitch Formula (2)

| Material to be Broached | Depth d of Cut per Tooth, Inch | | | | | Pressure P , Side-cutting Broaches |
|---------------------------|--------------------------------------|-------|-------|-------|-------|--------------------------------------|
| | 0.024 | 0.010 | 0.004 | 0.002 | 0.001 | |
| | Pressure P in Tons per Square Inch | | | | | |
| Steel, High Ten. Strength | ... | ... | ... | 250 | 312 | 200–004"cut |
| Steel, Med. Ten. Strength | ... | ... | 158 | 185 | 243 | 143–006"cut |
| Cast Steel | ... | ... | 128 | 158 | ... | 115–006"cut |
| Malleable Iron | ... | ... | 108 | 128 | ... | 100–006"cut |
| Cast Iron | ... | 115 | 115 | 143 | ... | 115–020"cut |
| Cast Brass | ... | 50 | 50 | ... | ... | ... |
| Brass, Hot Pressed | ... | 85 | 85 | ... | ... | ... |
| Zinc Die Castings | ... | 70 | 70 | ... | ... | ... |
| Cast Bronze | 35 | 35 | ... | ... | ... | ... |
| Wrought Aluminum | ... | 70 | 70 | ... | ... | ... |
| Cast Aluminum | ... | 85 | 85 | ... | ... | ... |
| Magnesium Alloy | 35 | 35 | ... | ... | ... | ... |

The minimum pitch shown by Formula (1) is based upon the receiving capacity of the chip space. The minimum, however, should not be less than 0.2 inch unless a smaller pitch is required for exceptionally short cuts to provide at least two teeth in contact simultaneously, with the part being broached. A reduction below 0.2 inch is seldom required in surface broaching but it may be necessary in connection with internal broaching.

$$\text{Minimum pitch} = 3\sqrt{LdF} \quad (1)$$

Whether the minimum pitch may be used or not depends upon the power of the available machine. The factor F in the formula provides for the increase in volume as the material is broached into chips. If a broach has adjustable inserts for the finishing teeth, the pitch of the finishing teeth may be smaller than the pitch of the roughing teeth because of the smaller depth d of the cut. The higher value of F for finishing teeth prevents the pitch from becoming too small, so that the spirally curled chips will not be crowded into too small a space.

The pitch of the roughing and finishing teeth should be equal for broaches without separate inserts (notwithstanding the different values of d and F) so that some of the finishing teeth may be ground into roughing teeth after wear makes this necessary.

$$\text{Allowable pitch} = \frac{dLbP}{T} \quad (2)$$

If the pitch obtained by Formula (2) is larger than the minimum obtained by Formula (1), this larger value should be used because it is based upon the usable power of the machine. As the notation indicates, 70 per cent of the maximum tonnage T is taken as the usable capacity. The 30 per cent reduction is to provide a margin for the increase in broaching load resulting from the gradual dulling of the cutting edges.

Table 3. Causes of Broaching Difficulties

| Broaching Difficulty | Possible Causes |
|--|---|
| Stuck broach | <p>Insufficient machine capacity; dulled teeth; clogged chip gullets; failure of power during cutting stroke.</p> <p>To remove a stuck broach, workpiece and broach are removed from the machine as a unit; never try to back out broach by reversing machine. If broach does not loosen by tapping workpiece lightly and trying to slide it off its starting end, mount workpiece and broach in a lathe and turn down workpiece to the tool surface. Workpiece may be sawed longitudinally into several sections in order to free the broach.</p> <p>Check broach design, perhaps tooth relief (back off) angle is too small or depth of cut per tooth is too great.</p> |
| Galling and pickup | <p>Lack of homogeneity of material being broached—uneven hardness, porosity; improper or insufficient coolant; poor broach design, mutilated broach; dull broach; improperly sharpened broach; improperly designed or outworn fixtures.</p> <p>Good broach design will do away with possible chip build-up on tooth faces and excessive heating. Grinding of teeth should be accurate so that the correct gullet contour is maintained. Contour should be fair and smooth.</p> |
| Broach breakage | <p>Overloading; broach dullness; improper sharpening; interrupted cutting stroke; backing up broach with workpiece in fixture; allowing broach to pass entirely through guide hole; ill fitting and/or sharp edged key; crooked holes; untrue locating surface; excessive hardness of workpiece; insufficient clearance angle; sharp corners on pull end of broach.</p> <p>When grinding bevels on pull end of broach use wheel that is not too pointed.</p> |
| Chatter | <p>Too few teeth in cutting contact simultaneously; excessive hardness of material being broached; loose or poorly constructed tooling; surging of ram due to load variations.</p> <p>Chatter can be alleviated by changing the broaching speed, by using shear cutting teeth instead of right angle teeth, and by changing the coolant and the face and relief angles of the teeth.</p> |
| Drifting or misalignment of tool during cutting stroke | Lack of proper alignment when broach is sharpened in grinding machine, which may be caused by dirt in the female center of the broach; inadequate support of broach during the cutting stroke, on a horizontal machine especially; body diameter too small; cutting resistance variable around I.D. of hole due to lack of symmetry of surfaces to be cut; variations in hardness around I.D. of hole; too few teeth in cutting contact. |
| Streaks in broached surface | Lands too wide; presence of forging, casting or annealing scale; metal pickup; presence of grinding burrs and grinding and cleaning abrasives. |
| Rings in the broached hole | Due to surging resulting from uniform pitch of teeth; presence of sharpening burrs on broach; tooth clearance angle too large; locating face not smooth or square; broach not supported for all cutting teeth passing through the work. The use of differential tooth spacing or shear cutting teeth helps in preventing surging. Sharpening burrs on a broach may be removed with a wood block. |

CUTTING TOOLS FOR TURNING

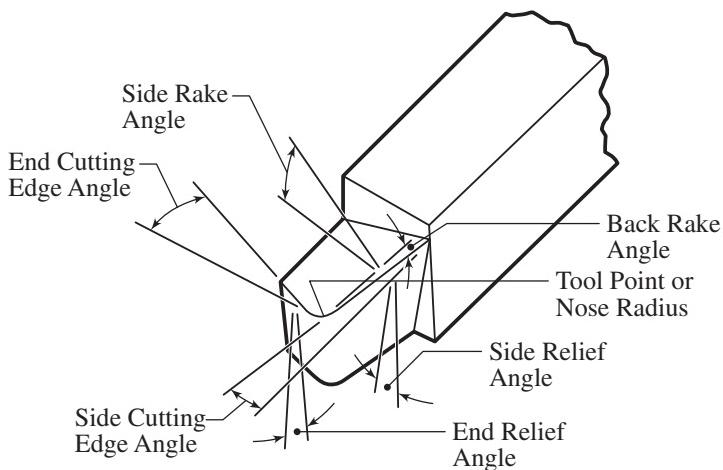


Fig. 1. Terms Applied to Single-point Turning Tools

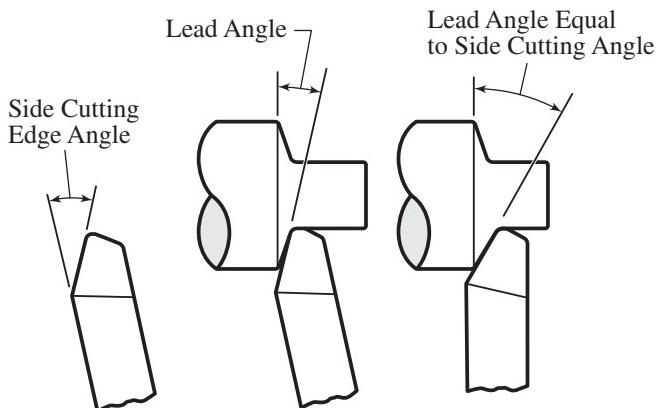


Fig. 2. Lead Angle on Single-point Turning Tool

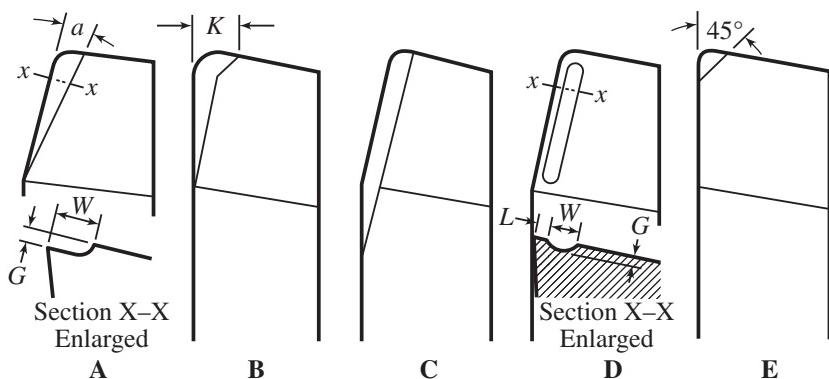


Fig. 3. Different Forms of Chipbreakers for Turning Tools

Chipbreakers.—Angular Shoulder Type: Angle a between the shoulder and cutting edge may vary from 6 to 15 degrees or more, 8 degrees being a fair average. The ideal angle, width W and depth G , depend upon the speed and feed, the depth of cut, and the material. As a general rule, width W , at the end of the tool, varies from $\frac{3}{32}$ to $\frac{7}{32}$ inch, and the depth G may range from $\frac{1}{64}$ to $\frac{1}{16}$ inch. The shoulder radius equals depth G . If the tool has a large nose radius, the corner of the shoulder at the nose end may be beveled off, as illustrated at B , to prevent it from coming into contact with the work. The width K for type B should equal approximately 1.5 times the nose radius.

Parallel Shoulder Type: Diagram C shows a design with a chipbreaking shoulder that is parallel with the cutting edge. With this form, the chips are likely to come off in short curled sections. The parallel form may also be applied to straight tools which do not have a side cutting-edge angle. The tendency with this parallel shoulder form is to force the chips against the work and damage it.

Groove Type: This type (diagram D) has a groove in the face of the tool produced by grinding. Between the groove and the cutting edge, there is a land L . Under ideal conditions, this width L , the groove width W , and the groove depth G , would be varied to suit the feed, depth of cut and material. For average use, L is about $\frac{1}{32}$ inch; G , $\frac{1}{32}$ inch; and W , $\frac{1}{16}$ inch. There are differences of opinion concerning the relative merits of the groove type and the shoulder type. Both types have proved satisfactory when properly proportioned for a given class of work.

Chipbreaker for Light Cuts: Diagram E illustrates a form of chipbreaker that is sometimes used on tools for finishing cuts having a maximum depth of about $\frac{1}{32}$ inch. This chipbreaker is a shoulder type having an angle of 45 degrees and a maximum width of about $\frac{1}{16}$ inch. It is important in grinding all chipbreakers to give the chip-bearing surfaces a fine finish, such as would be obtained by honing. This finish greatly increases the life of the tool.

Identification System for Indexable Inserts.—The size of indexable inserts is determined by the diameter of an inscribed circle (I.C.), except for rectangular and parallelogram inserts where the length and width dimensions are used. To describe an insert in its entirety, a standard ANSI B212.4-2002 identification system is used where each position number designates a feature of the insert. The ANSI Standard includes items now commonly used and facilitates identification of items not in common use. Identification consists of up to ten positions; each position defines a characteristic of the insert as shown below:

| | | | | | | | | | |
|---|---|---|---|---|---|---|----------------|----------------|-----------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 ^a | 9 ^a | 10 ^a |
| T | N | M | G | 5 | 4 | 3 | | | A |

^aEighth, Ninth, and Tenth Positions are used only when required.

Shape: The shape of an insert is designated by a letter: **R** for round; **S**, square; **T**, triangle; **A**, 85° parallelogram; **B**, 82° parallelogram; **C**, 80° diamond; **D**, 55° diamond; **E**, 75° diamond; **H**, hexagon; **K**, 55° parallelogram; **L**, rectangle; **M**, 86° diamond; **O**, octagon; **P**, pentagon; **V**, 35° diamond; and **W**, 80° trigon.

Relief Angle (Clearances): The second position is a letter denoting the relief angles; **N** for 0°; **A**, 3°; **B**, 5°; **C**, 7°; **P**, 11°; **D**, 15°; **E**, 20°; **F**, 25°; **G**, 30°; **H**, 0° & 11°*; **J**, 0° & 14°*; **K**, 0° & 17°*; **L**, 0° & 20°*; **M**, 11° & 14°*; **R**, 11° & 17°*; **S**, 11° & 20°*. When mounted on a holder, the actual relief angle may be different from that on the insert.

Tolerances: The third position is a letter and indicates the tolerances which control the indexability of the insert. Tolerances specified do not imply the method of manufacture.

Type: The type of insert is designated by a letter. **A**, with hole; **B**, with hole and countersink; **C**, with hole and two countersinks; **F**, chip grooves both surfaces, no hole; **G**, same as

* Second angle is secondary facet angle, which may vary by $\pm 1^\circ$.

F but with hole; **H**, with hole, one countersink, and chip groove on one rake surface; **J**, with hole, two countersinks and chip grooves on two rake surfaces; **M**, with hole and chip groove on one rake surface; **N**, without hole; **Q**, with hole and two countersinks; **R**, without hole but with chip groove on one rake surface; **T**, with hole, one countersink, and chip groove on one rake face; **U**, with hole, two countersinks, and chip grooves on two rake faces; and **W**, with hole and one countersink. *Note:* a dash may be used after position 4 to separate the shape-describing portion from the following dimensional description of the insert and is not to be considered a position in the standard description.

Size: The size of the insert is designated by a one- or a two-digit number. For regular polygons and diamonds, it is the number of eighths of an inch in the nominal size of the inscribed circle, and will be a one- or two-digit number when the number of eighths is a whole number. It will be a two-digit number, including one decimal place, when it is not a whole number. Rectangular and parallelogram inserts require two digits: the first digit indicates the number of eighths of an inch width and the second digit, the number of quarters of an inch length.

Thickness: The thickness is designated by a one- or two-digit number, which indicates the number of sixteenths of an inch in the thickness of the insert. It is a one-digit number when the number of sixteenths is a whole number; it is a two-digit number carried to one decimal place when the number of sixteenths of an inch is not a whole number.

Cutting Point Configuration: The cutting point, or nose radius, is designated by a number representing $\frac{1}{64}$ ths of an inch; a flat at the cutting point or nose, is designated by a letter: **0** for sharp corner; **1**, $\frac{1}{64}$ inch radius; **2**, $\frac{1}{32}$ inch radius; **3**, $\frac{3}{64}$ inch radius; **4**, $\frac{1}{16}$ inch radius; **5**, $\frac{5}{64}$ inch radius; **6**, $\frac{3}{32}$ inch radius; **7**, $\frac{7}{64}$ inch radius; **8**, $\frac{1}{8}$ inch radius; **A**, square insert with 45° chamfer; **D**, square insert with 30° chamfer; **E**, square insert with 15° chamfer; **F**, square insert with 3° chamfer; **K**, square insert with 30° double chamfer; **L**, square insert with 15° double chamfer; **M**, square insert with 3° double chamfer; **N**, truncated triangle insert; and **P**, flattened corner triangle insert.

Special Cutting Point Definition:: The eighth position, if it follows a letter in the 7th position, is a number indicating the number of $\frac{1}{64}$ ths of an inch measured parallel to the edge of the facet.

Hand:: **R**, right; **L**, left; to be used when required in ninth position.

Other Conditions: The tenth position defines special conditions (such as edge treatment, surface finish) as follows: **A**, honed, 0.0005 inch to less than 0.003 inch; **B**, honed, 0.003 inch to less than 0.005 inch; **C**, honed, 0.005 inch to less than 0.007 inch; **J**, polished, 4 microinch arithmetic average (AA) on rake surfaces only; **T**, chamfered, manufacturer's standard negative land, rake face only.

| Symbol | Tolerance (\pm from nominal) | | Symbol | Tolerance (\pm from nominal) | |
|----------|---------------------------------|-----------------|----------|---------------------------------|-----------------|
| | Inscribed Circle, Inch | Thickness, Inch | | Inscribed Circle, Inch | Thickness, Inch |
| A | 0.001 | 0.001 | H | 0.0005 | 0.001 |
| B | 0.001 | 0.005 | J | 0.002–0.005 | 0.001 |
| C | 0.001 | 0.001 | K | 0.002–0.005 | 0.001 |
| D | 0.001 | 0.005 | L | 0.002–0.005 | 0.001 |
| E | 0.001 | 0.001 | M | 0.002–0.004 ^a | 0.005 |
| F | 0.0005 | 0.001 | U | 0.005–0.010 ^a | 0.005 |
| G | 0.001 | 0.005 | N | 0.002–0.004 ^a | 0.001 |

^aExact tolerance is determined by size of insert. See ANSI B94.25.

Table 1. Standard Shank Sizes for Indexable Insert Holders

| Basic Shank Size | Shank Dimensions for Indexable Insert Holders | | | | | |
|---|---|-------|-------|-------|----------------|--------|
| | A | | B | | C ^a | |
| | In. | mm | In. | mm | In. | mm |
| $\frac{1}{2} \times \frac{1}{2} \times 4\frac{1}{2}$ | 0.500 | 12.70 | 0.500 | 12.70 | 4.500 | 114.30 |
| $\frac{5}{8} \times \frac{5}{8} \times 4\frac{1}{2}$ | 0.625 | 15.87 | 0.625 | 15.87 | 4.500 | 114.30 |
| $\frac{5}{8} \times 1\frac{1}{4} \times 6$ | 0.625 | 15.87 | 1.250 | 31.75 | 6.000 | 152.40 |
| $\frac{3}{4} \times \frac{3}{4} \times 4\frac{1}{2}$ | 0.750 | 19.05 | 0.750 | 19.05 | 4.500 | 114.30 |
| $\frac{3}{4} \times 1 \times 6$ | 0.750 | 19.05 | 1.000 | 25.40 | 6.000 | 152.40 |
| $\frac{3}{4} \times 1\frac{1}{4} \times 6$ | 0.750 | 19.05 | 1.250 | 31.75 | 6.000 | 152.40 |
| $1 \times 1 \times 6$ | 1.000 | 25.40 | 1.000 | 25.40 | 6.000 | 152.40 |
| $1 \times 1\frac{1}{4} \times 6$ | 1.000 | 25.40 | 1.250 | 31.75 | 6.000 | 152.40 |
| $1 \times 1\frac{1}{2} \times 6$ | 1.000 | 25.40 | 1.500 | 38.10 | 6.000 | 152.40 |
| $1\frac{1}{4} \times 1\frac{1}{4} \times 7$ | 1.250 | 31.75 | 1.250 | 31.75 | 7.000 | 177.80 |
| $1\frac{1}{4} \times 1\frac{1}{2} \times 8$ | 1.250 | 31.75 | 1.500 | 38.10 | 8.000 | 203.20 |
| $1\frac{3}{8} \times 2\frac{1}{16} \times 6\frac{3}{8}$ | 1.375 | 34.92 | 2.062 | 52.37 | 6.380 | 162.05 |
| $1\frac{1}{2} \times 1\frac{1}{2} \times 7$ | 1.500 | 38.10 | 1.500 | 38.10 | 7.000 | 177.80 |
| $1\frac{3}{4} \times 1\frac{3}{4} \times 9\frac{1}{2}$ | 1.750 | 44.45 | 1.750 | 44.45 | 9.500 | 241.30 |
| $2 \times 2 \times 8$ | 2.000 | 50.80 | 2.000 | 50.80 | 8.000 | 203.20 |

^aHolder length; may vary by manufacturer. Actual shank length depends on holder style.

Identification System for Indexable Insert Holders: The following identification system conforms to the American National Standard, ANSI B212.5-2002, Metric Holders for Indexable Inserts.

Each position in the system designates a feature of the holder in the following sequence:

1 2 3 4 5 — 6 — 7 — 8^a — 9 — 10^a
C **T** **N** **A** **R** — **85** — **25** — **D** — **16** — **Q**

1) *Method of Holding Horizontally Mounted Insert:* The method of holding or clamping is designated by a letter: **C**, top clamping, insert without hole; **M**, top and hole clamping, insert with hole; **P**, hole clamping, insert with hole; **S**, screw clamping through hole, insert with hole; **W**, wedge clamping.

2) *Insert Shape:* The insert shape is identified by a letter: **H**, hexagonal; **O**, octagonal; **P**, pentagonal; **S**, square; **T**, triangular; **C**, rhombic, 80° included angle; **D**, rhombic, 55° included angle; **E**, rhombic, 75° included angle; **M**, rhombic, 86° included angle; **V**, rhombic, 35° included angle; **W**, hexagonal, 80° included angle; **L**, rectangular; **A**, parallelogram, 85° included angle; **B**, parallelogram, 82° included angle; **K**, parallelogram, 55° included angle; **R**, round. The included angle is always the smaller angle.

3) *Holder Style:* The holder style designates the shank style and the side cutting edge angle, or end cutting edge angle, or the purpose for which the holder is used. It is designated by a letter: **A**, for straight shank with 0° side cutting edge angle; **B**, straight shank with 15° side cutting edge angle; **C**, straight-shank end cutting tool with 0° end cutting edge angle; **D**, straight shank with 45° side cutting edge angle; **E**, straight shank with 30°

side cutting edge angle; **F**, offset shank with 0° end cutting edge angle; **G**, offset shank with 0° side cutting edge angle; **J**, offset shank with negative 3° side cutting edge angle; **K**, offset shank with 15° end cutting edge angle; **L**, offset shank with negative 5° side cutting edge angle and 5° end cutting edge angle; **M**, straight shank with 40° side cutting edge angle; **N**, straight shank with 27° side cutting edge angle; **R**, offset shank with 15° side cutting edge angle; **S**, offset shank with 45° side cutting edge angle; **T**, offset shank with 30° side cutting edge angle; **U**, offset shank with negative 3° end cutting edge angle; **V**, straight shank with $17\frac{1}{2}^\circ$ side cutting edge angle; **W**, offset shank with 30° end cutting edge angle; **Y**, offset shank with 5° end cutting edge angle.

4) *Normal Clearances*: The normal clearances of inserts are identified by letters: **A**, 3° ; **B**, 5° ; **C**, 7° ; **D**, 15° ; **E**, 20° ; **F**, 25° ; **G**, 30° ; **N**, 0° ; **P**, 11° .

5) *Hand of tool*: The hand of the tool is designated by a letter: **R** for right-hand; **L**, left-hand; and **N**, neutral, or either hand.

6) *Tool Height for Rectangular Shank Cross Sections*: The tool height for tool holders with a rectangular shank cross section and the height of cutting edge equal to shank height is given as a two-digit number representing this value in millimeters. For example, a height of 32 mm would be encoded as 32; 8 mm would be encoded as 08, where the one-digit value is preceded by a zero.

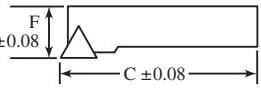
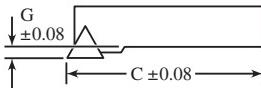
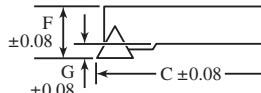
7) *Tool Width for Rectangular Shank Cross Sections*: The tool width for tool holders with a rectangular shank cross section is given as a two-digit number representing this value in millimeters. For example, a width of 25 mm would be encoded as 25; 8 mm would be encoded as 08, where the one-digit value is preceded by a zero.

8) *Tool Length*: The tool length is designated by a letter: **A**, 32 mm; **B**, 40 mm; **C**, 50 mm; **D**, 60 mm; **E**, 70 mm; **F**, 80 mm; **G**, 90 mm; **H**, 100 mm; **J**, 110 mm; **K**, 125 mm; **L**, 140 mm; **M**, 150 mm; **N**, 160 mm; **P**, 170 mm; **Q**, 180 mm; **R**, 200 mm; **S**, 250 mm; **T**, 300 mm; **U**, 350 mm; **V**, 400 mm; **W**, 450 mm; **X**, special length to be specified; **Y**, 500 mm.

9) **Indexable Insert Size**: The size of indexable inserts is encoded as follows: For insert shapes C, D, E, H, M, O, P, R, S, T, V, the side length (the diameter for R inserts) in millimeters is used as a two-digit number, with decimals being disregarded. For example, the symbol for a side length of 16.5 mm is 16. For insert shapes A, B, K, L, the length of the main cutting edge or of the longer cutting edge in millimeters is encoded as a two-digit number, disregarding decimals. If the symbol obtained has only one digit, then it should be preceded by a zero. For example, the symbol for a main cutting edge of 19.5 mm is 19; for an edge of 9.5 mm, the symbol is 09.

10) *Special Tolerances*: Special tolerances are indicated by a letter: **Q**, back and end qualified tool; **F**, front and end qualified tool; **B**, back, front, and end qualified tool. A qualified tool is one that has tolerances of ± 0.08 mm for dimensions F, G, and C. (See Table 2.)

Table 2. Letter Symbols for Qualification of Tool Holders — Position 10
ANSI B212.5-2002

| Letter Symbol | | |
|--|---|---|
| Q | F | B |
| Back and end qualified tool  | Front and end qualified tool  | Back, front, and end qualified tool  |

Indexable Insert Holders for NC: Indexable insert holders for numerical control lathes are usually made to more precise standards than ordinary holders. Where applicable, reference should be made to American National Standard B212.3-1986, Precision Holders for Indexable Inserts. This standard covers the dimensional specifications, styles, and designations of precision holders for indexable inserts, which are defined as tool holders that locate the gage insert (a combination of shim and insert thicknesses) from the back or front and end surfaces to a specified dimension with a ± 0.003 inch (± 0.08 mm) tolerance. In NC programming, the programmed path is that followed by the center of the tool tip, which is the center of the point, or nose radius, of the insert. The surfaces produced are the result of the path of the nose and the major cutting edge, so it is necessary to compensate for the nose or point radius and the lead angle when writing the program. Table 3, from B212.3, gives the compensating dimensions for different holder styles. The reference point is determined by the intersection of extensions from the major and minor cutting edges, which would be the location of the point of a sharp pointed tool. The distances from this point to the nose radius are L_1 and D_1 ; L_2 and D_2 are the distances from the sharp point to the center of the nose radius. Threading tools have sharp corners and do not require a radius compensation. Other dimensions of importance in programming threading tools are also given in Table 4; the data were developed by Kennametal, Inc.

Table 3. Insert Radius Compensation ANSI B212.3-1986

| Square Profile | | | | | |
|--|------------------------|-------------|-------------|-------------|-------------|
| B Style ^a Also Applies to R Style | Turning 15° Lead Angle | | | | |
| | Rad. | <i>L</i> -1 | <i>L</i> -2 | <i>D</i> -1 | <i>D</i> -2 |
| | $\frac{1}{64}$ | 0.0035 | 0.0191 | 0.0009 | 0.0110 |
| | $\frac{1}{32}$ | 0.0070 | 0.0383 | 0.0019 | 0.0221 |
| | $\frac{3}{64}$ | 0.0105 | 0.0574 | 0.0028 | 0.0331 |
| D Style ^a Also Applies to S Style | Turning 45° Lead Angle | | | | |
| | Rad. | <i>L</i> -1 | <i>L</i> -2 | <i>D</i> -1 | <i>D</i> -2 |
| | $\frac{1}{64}$ | 0.0065 | 0.0221 | 0.0065 | 0 |
| | $\frac{1}{32}$ | 0.0129 | 0.0442 | 0.0129 | 0 |
| | $\frac{3}{64}$ | 0.0194 | 0.0663 | 0.0194 | 0 |
| K Style ^a | Facing 15° Lead Angle | | | | |
| | Rad. | <i>L</i> -1 | <i>L</i> -2 | <i>D</i> -1 | <i>D</i> -2 |
| | $\frac{1}{64}$ | 0.0009 | 0.0110 | 0.0035 | 0.0191 |
| | $\frac{1}{32}$ | 0.0019 | 0.0221 | 0.0070 | 0.0383 |
| | $\frac{3}{64}$ | 0.0028 | 0.0331 | 0.0105 | 0.0574 |
| G Style ^a | Turning 0° Lead Angle | | | | |
| | Rad. | <i>L</i> -1 | <i>L</i> -2 | <i>D</i> -1 | <i>D</i> -2 |
| | $\frac{1}{64}$ | 0.0114 | 0.0271 | 0 | 0.0156 |
| | $\frac{1}{32}$ | 0.0229 | 0.0541 | 0 | 0.0312 |
| | $\frac{3}{64}$ | 0.0343 | 0.0812 | 0 | 0.0469 |
| | $\frac{1}{16}$ | 0.0458 | 0.1082 | 0 | 0.0625 |
| Triangle Profile | | | | | |
| G Style ^a | Turning 0° Lead Angle | | | | |
| | Rad. | <i>L</i> -1 | <i>L</i> -2 | <i>D</i> -1 | <i>D</i> -2 |
| | $\frac{1}{64}$ | 0.0114 | 0.0271 | 0 | 0.0156 |
| | $\frac{1}{32}$ | 0.0229 | 0.0541 | 0 | 0.0312 |
| | $\frac{3}{64}$ | 0.0343 | 0.0812 | 0 | 0.0469 |
| | $\frac{1}{16}$ | 0.0458 | 0.1082 | 0 | 0.0625 |

Table 3. (Continued) Insert Radius Compensation ANSI B212.3-1986

| | | Square Profile | | | | |
|--|------------------------|--|--------|--------|--------|--------|
| | | Turning and Facing 15° Lead Angle | | | | |
| Style ^a : Also Applies to R Style | F Style ^a : | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0.0146 | 0.0302 | 0.0039 | 0.0081 |
| | | $\frac{1}{32}$ | 0.0291 | 0.0604 | 0.0078 | 0.0162 |
| | | $\frac{3}{64}$ | 0.0437 | 0.0906 | 0.0117 | 0.0243 |
| | | $\frac{1}{16}$ | 0.0582 | 0.1207 | 0.0156 | 0.0324 |
| J Style ^a : | | Facing 90° Lead Angle | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0 | 0.0156 | 0.0114 | 0.0271 |
| | | $\frac{1}{32}$ | 0 | 0.0312 | 0.0229 | 0.0541 |
| | | $\frac{3}{64}$ | 0 | 0.0469 | 0.0343 | 0.0812 |
| G Style ^a : | L Style ^a : | Turning & Facing 3° Lead Angle | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0.0106 | 0.0262 | 0.0014 | 0.0170 |
| | | $\frac{1}{32}$ | 0.0212 | 0.0524 | 0.0028 | 0.0340 |
| | | $\frac{3}{64}$ | 0.0318 | 0.0786 | 0.0042 | 0.0511 |
| F Style ^a : | | 80° Diamond Profile | | | | |
| | | Turning & Facing 0° Lead Angle | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0.0030 | 0.0186 | 0 | 0.0156 |
| | | $\frac{1}{32}$ | 0.0060 | 0.0312 | 0 | 0.0312 |
| F Style ^a : | | Turning & Facing 5° Reverse Lead Angle | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0.0016 | 0.0172 | 0.0016 | 0.0172 |
| | | $\frac{1}{32}$ | 0.0031 | 0.0344 | 0.0031 | 0.0344 |
| | | $\frac{3}{64}$ | 0.0047 | 0.0516 | 0.0047 | 0.0516 |
| F Style ^a : | | Facing 0° Lead Angle | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 |
| | | $\frac{1}{64}$ | 0 | 0.0156 | 0.0030 | 0.0186 |
| | | $\frac{1}{32}$ | 0 | 0.0312 | 0.0060 | 0.0372 |
| | | $\frac{3}{64}$ | 0 | 0.0469 | 0.0090 | 0.0559 |
| F Style ^a : | | $\frac{1}{16}$ | 0 | 0.0625 | 0.0120 | 0.0745 |

Table 3. (Continued) Insert Radius Compensation ANSI B212.3-1986

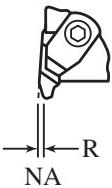
| | | Square Profile | | | | | |
|---|--|---------------------------------|--------|--------|--------|--------|--|
| | | Turning 15° Lead Angle | | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 | |
| R Style ^a : | | $\frac{1}{64}$ | 0.0011 | 0.0167 | 0.0003 | 0.0117 | |
| | | $\frac{1}{32}$ | 0.0022 | 0.0384 | 0.0006 | 0.0234 | |
| | | $\frac{3}{64}$ | 0.0032 | 0.0501 | 0.0009 | 0.0351 | |
| | | $\frac{1}{16}$ | 0.0043 | 0.0668 | 0.0012 | 0.0468 | |
| | | Facing 15° Lead Angle | | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 | |
| K Style ^a : | | $\frac{1}{64}$ | 0.0003 | 0.0117 | 0.0011 | 0.0167 | |
| | | $\frac{1}{32}$ | 0.0006 | 0.0234 | 0.0022 | 0.0334 | |
| | | $\frac{3}{64}$ | 0.0009 | 0.0351 | 0.0032 | 0.0501 | |
| | | $\frac{1}{16}$ | 0.0012 | 0.0468 | 0.0043 | 0.0668 | |
| 55° Profile | | | | | | | |
| | | Profiling 3° Reverse Lead Angle | | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 | |
| J Style ^a : | | $\frac{1}{64}$ | 0.0135 | 0.0292 | 0.0015 | 0.0172 | |
| | | $\frac{1}{32}$ | 0.0271 | 0.0583 | 0.0031 | 0.0343 | |
| | | $\frac{3}{64}$ | 0.0406 | 0.0875 | 0.0046 | 0.0519 | |
| | | $\frac{1}{16}$ | 0.0541 | 0.1166 | 0.0062 | 0.0687 | |
| 35° Profile | | | | | | | |
| | | Profiling 3° Reverse Lead Angle | | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 | |
| J Style ^a ; Negative rake holders have 6° back rake and 6° side rake | | $\frac{1}{64}$ | 0.0330 | 0.0487 | 0.0026 | 0.0182 | |
| | | $\frac{1}{32}$ | 0.0661 | 0.0973 | 0.0051 | 0.0364 | |
| | | $\frac{3}{64}$ | 0.0991 | 0.1460 | 0.0077 | 0.0546 | |
| | | $\frac{1}{16}$ | 0.1322 | 0.1947 | 0.0103 | 0.0728 | |
| | | Profiling 5° Lead Angle | | | | | |
| | | Rad. | L-1 | L-2 | D-1 | D-2 | |
| L Style ^a : | | $\frac{1}{64}$ | 0.0324 | 0.0480 | 0.0042 | 0.0198 | |
| | | $\frac{1}{32}$ | 0.0648 | 0.0360 | 0.0086 | 0.0398 | |
| | | $\frac{3}{64}$ | 0.0971 | 0.1440 | 0.0128 | 0.0597 | |
| | | $\frac{1}{16}$ | 0.1205 | 0.1920 | 0.0170 | 0.0795 | |

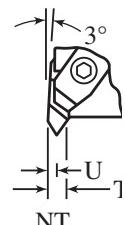
^a L-1 and D-1 over sharp point to nose radius; and L-2 and D-2 over sharp point to center of nose radius. The D-1 dimension for the B, E, D, M, P, S, T, and V style tools are over the sharp point of insert to a sharp point at the intersection of a line on the lead angle on the cutting edge of the insert and the C dimension. The L-1 dimensions on K style tools are over the sharp point of insert to sharp point intersection of lead angle and F dimensions.

All dimensions are in inches.

Table 4. Threading Tool Insert Radius Compensation for NC Programming

| Threading | | | | | | |
|-------------|-----------|-------|-------|-------|-------|-------|
| Insert Size | T | R | U | Y | X | Z |
| 2 | 5/32 Wide | 0.040 | 0.075 | 0.040 | 0.024 | 0.140 |
| 3 | 3/16 Wide | 0.046 | 0.098 | 0.054 | 0.031 | 0.183 |
| 4 | 1/4 Wide | 0.053 | 0.128 | 0.054 | 0.049 | 0.239 |
| 5 | 5/8 Wide | 0.099 | 0.190 | ... | ... | ... |

| | | | |
|---|---|---|---|
| Buttress Threading | 29° Acme | 60° V-Threading | |
|  |  |  |  |
| NTB-B | NTB-A | NA | NTF |

| | |
|--|----|
|  | |
| U | NT |

All dimensions are given in inches.

Courtesy of Kennametal, Inc.

The *C* and *F* characters are tool holder dimensions other than the shank size. In all instances, the *C* dimension is parallel to the length of the shank and the *F* dimension is parallel to the side dimension; actual dimensions must be obtained from the manufacturer. For all *K* style holders, the *C* dimension is the distance from the end of the shank to the tangent point of the nose radius and the end cutting edge of the insert. For all other holders, the *C* dimension is from the end of the shank to a tangent to the nose radius of the insert. The *F* dimension on all *B*, *D*, *E*, *M*, *P*, and *V* style holders is measured from the back side of the shank to the tangent point of the nose radius and the side cutting edge of the insert. For all *A*, *F*, *G*, *J*, *K*, and *L* style holders, the *F* dimension is the distance from the back side of the shank to the tangent of the nose radius of the insert. In all these designs, the nose radius is the standard radius corresponding to those given in the paragraph *Cutting Point Configuration* on page 169.

Table 5. Cemented Carbides

| Composition | Features | Comments |
|---|---|--|
| Tungsten Carbide/Cobalt (WC/Co) | No porosity should be visible under the highest magnification. Has the greatest resistance to simple abrasive wear | Hardness and abrasion resistance increases as the Co content is lowered (minimum 2-3%). Tougher and less hard grades are obtained as carbide grain or cobalt content are both increased. |
| Tungsten-Titanium Carbide/Cobalt (WC/TiC/Co) | Used to cut steels and other ferrous alloys. Considerably more brittle and less abrasion resistant than tungsten carbide. | Resists the high-temperature diffusive attack that causes chemical breakdown and cratering. |
| Tungsten-Titanium- Tantalum (-Niobium) Carbide/Cobalt | Used mainly for cutting steels. Improve on the best features of WC/TiC/Co. Can undertake very heavy cuts at high speeds on all types of steels, including austenitic stainless. Also operate well on ductile cast irons and nickel-base super alloys. | Except for coated carbides these could be the most popular class of hardmetals. Do not have the resistance to abrasive wear possessed by micrograin straight tungsten carbide grades nor the good resistance to cratering of coated grades and titanium carbide-based cermets. |
| Steel- and Alloy-Bonded Titanium Carbide | Used for stamping, blanking and drawing dies, machine components, and similar items where the ability to machine before hardening reduces production costs substantially. | Characterized by high binder contents (typically 50-60% by volume) and lower hardness, compared with the more usual hardmetals, and by great variation in properties obtained by heat treatment. Consists primarily of titanium carbide bonded with heat-treated steel, but some grades also contain tungsten carbide or are bonded with nickel- or copper-based alloys. |

Table 6. ISO Classifications of Hardmetals (Cemented Carbides and Carbonitrides) by Application

| Main Types of Chip Removal | | Groups of Applications | | | | Direction of Decrease in Characteristic | | | |
|----------------------------|--|------------------------|---|--|--|---|----------------------------------|--|--|
| Symbol and Color | Broad Categories of Materials to be Machined | Designation (Grade) | Specific Material to be Machined | Use and Working Conditions | | of cut | of carbide | | |
| P Blue | Ferrous with long chips | P01 | Steel, steel castings | Finish turning and boring; high cutting speeds, small chip sections, accurate dimensions, fine finish, vibration-free operations | | ↑ speed ↓ feed | ↑ wear resistance ↓ toughness | | |
| | | P10 | | Turning, copying, threading, milling; high cutting speeds; small or medium chip sections | | | | | |
| | | P20 | Steel, steel castings, ductile cast iron with long chips | Turning, copying, milling; medium cutting speeds and chip sections, planing with small chip sections | | | | | |
| | | P30 | | Turning, milling, planing; medium or large chip sections, unfavorable machining conditions | | | | | |
| | | P40 | Steel, steel castings with sand inclusions and cavities | Turning, planing, slotting; low cutting speeds, large chip sections, with possible large cutting angles, unfavorable cutting conditions, and work on automatic machines | | | | | |
| | | P50 | Steel, steel castings of medium or low tensile strength, with sand inclusions and cavities | Operations demanding very tough carbides; turning, planing, slotting; low cutting speeds, large chip sections, with possible large cutting angles, unfavorable conditions and work on automatic machines | | | | | |
| M Yellow | Ferrous metals with long or short chips, and non ferrous metals | M10 | Steel, steel castings, manganese steel, gray cast iron, alloy cast iron | Turning; medium or high cutting speeds, small or medium chip sections | | ↑ wear resistance ↓ toughness | ↑ wear resistance ↓ toughness | | |
| | | M20 | Steel, steel castings, austenitic or manganese steel, gray cast iron | Turning, milling; medium cutting speeds and chip sections | | | | | |
| | | M30 | Steel, steel castings, austenitic steel, gray cast iron, high-temperature-resistant alloys | Turning, milling, planing; medium cutting speeds, medium or large chip sections | | | | | |
| | | M40 | Mild, free-cutting steel, low-tensile steel, nonferrous metals and light alloys | Turning, parting off; particularly on automatic machines | | | | | |
| K Red | Ferrous metals with short chips, non-ferrous metals and non-metallic materials | K01 | Very hard gray cast iron, chilled castings over 85 Shore, high-silicon aluminum alloys, hardened steel, highly abrasive plastics, hard cardboard, ceramics | Turning, finish turning, boring, milling, scraping | | ↑ wear resistance ↓ toughness | ↑ wear resistance ↓ toughness | | |
| | | K10 | Gray cast iron over 220 Brinell, malleable cast iron with short chips, hardened steel, silicon-aluminum and copper alloys, plastics, glass, hard rubber, hard cardboard, porcelain, stone | Turning, milling, drilling, boring, broaching, scraping | | | | | |
| | | K20 | Gray cast iron up to 220 Brinell, nonferrous metals, copper, brass, aluminum | Turning, milling, planing, boring, broaching, demanding very tough carbide | | | | | |
| | | K30 | Low-hardness gray cast iron, low-tensile steel, compressed wood | Turning, milling, planing, slotting, unfavorable conditions, and possibility of large cutting angles | | | | | |
| | | K40 | Softwood or hard wood, nonferrous metals | | | | | | |

MACHINING OPERATIONS

Machining Aluminum.— Some of the alloys of aluminum have been machined successfully without any lubricant or cutting compound, but some form of lubricant is desirable to obtain the best results. For many purposes, a soluble cutting oil is good.

Tools for aluminum and aluminum alloys should have larger relief and rake angles than tools for cutting steel. For high-speed steel turning tools the following angles are recommended: relief angles, 14 to 16 degrees; back rake angle, 5 to 20 degrees; side rake angle, 15 to 35 degrees. For very soft alloys even larger side rake angles are sometimes used. High silicon aluminum alloys and some others have a very abrasive effect on the cutting tool. While these alloys can be cut successfully with high-speed-steel tools, cemented carbides are recommended because of their superior abrasion resistance. The tool angles recommended for cemented carbide turning tools are: relief angles, 12 to 14 degrees; back rake angle, 0 to 15 degrees; side rake angle, 8 to 30 degrees.

Cut-off tools and necking tools for machining aluminum and its alloys should have from 12 to 20 degrees back rake angle and the end relief angle should be from 8 to 12 degrees. Excellent threads can be cut with single-point tools in even the softest aluminum. Experience seems to vary somewhat regarding the rake angle for single-point thread cutting tools. Some prefer to use a rather large back and side rake angle although this requires a modification in the included angle of the tool to produce the correct thread contour. When both rake angles are zero, the included angle of the tool is ground equal to the included angle of the thread. Excellent threads have been cut in aluminum with zero rake angle thread-cutting tools using large relief angles, which are 16 to 18 degrees opposite the front side of the thread and 12 to 14 degrees opposite the back side of the thread. In either case, the cutting edges should be ground and honed to a keen edge. It is sometimes advisable to give the face of the tool a few strokes with a hone between cuts when chasing the thread to remove any built-up edge on the cutting edge.

Fine surface finishes are often difficult to obtain on aluminum and aluminum alloys, particularly the softer metals. When a fine finish is required, the cutting tool should be honed to a keen edge and the surfaces of the face and the flank will also benefit by being honed smooth. Tool wear is inevitable, but it should not be allowed to progress too far before the tool is changed or sharpened. A sulphurized mineral oil or a heavy-duty soluble oil will sometimes be helpful in obtaining a satisfactory surface finish. For best results, however, a diamond cutting tool is recommended. Excellent surface finishes can be obtained on even the softest aluminum and aluminum alloys with these tools.

Although ordinary milling cutters can be used successfully in shops where aluminum parts are only machined occasionally, the best results are obtained with coarse-tooth, large helix-angle cutters having large rake and clearance angles. Clearance angles up to 10 to 12 degrees are recommended. When slab milling and end milling a profile, using the peripheral teeth on the end mill, climb milling (also called down milling) will generally produce a better finish on the machined surface than conventional (or up) milling. Face milling cutters should have a large axial rake angle. Standard twist drills can be used without difficulty in drilling aluminum and aluminum alloys although high helix-angle drills are preferred. The wide flutes and high helix-angle in these drills helps to clear the chips. Sometimes split-point drills are preferred. Carbide tipped twist drills can be used for drilling aluminum and its alloys and may afford advantages in some production applications. Ordinary hand and machine taps can be used to tap aluminum and its alloys although spiral-fluted ground thread taps give superior results. Experience has shown that such taps should have a right-hand ground flute when intended to cut right-hand threads and the helix angle should be similar to that used in an ordinary twist drill.

Machining Magnesium.—Magnesium alloys are readily machined and with relatively low power consumption per cubic inch of metal removed. The usual practice is to employ high cutting speeds with relatively coarse feeds and deep cuts. Exceptionally fine finishes can be obtained so that grinding to improve the finish usually is unnecessary. The horsepower normally required in machining magnesium varies from 0.15 to 0.30 per cubic inch per minute. While this value is low, especially in comparison with power required for cast iron and steel, the total amount of power for machining magnesium usually is high because of the exceptionally rapid rate at which metal is removed.

Carbide tools are recommended for maximum efficiency, although high-speed steel frequently is employed. Tools should be designed so as to dispose of chips readily or without excessive friction, by employing polished chip-bearing surfaces, ample chip spaces, large clearances, and small contact areas. *Keen-edged tools should always be used.*

Feeds and Speeds for Magnesium: Speeds ordinarily range up to 5000 feet per minute for rough- and finish-turning, up to 3000 feet per minute for rough-milling, and up to 9000 feet per minute for finish-milling. For rough-turning, the following combinations of speed in feet per minute, feed per revolution, and depth of cut are recommended: Speed 300 to 600 feet per minute — feed 0.030 to 0.100 inch, depth of cut 0.5 inch; speed 600 to 1000 — feed 0.020 to 0.080, depth of cut 0.4; speed 1000 to 1500 — feed 0.010 to 0.060, depth of cut 0.3; speed 1500 to 2000 — feed 0.010 to 0.040, depth of cut 0.2; speed 2000 to 5000 — feed 0.010 to 0.030, depth of cut 0.15.

Lathe Tool Angles for Magnesium: The true or actual rake angle resulting from back and side rakes usually varies from 10 to 15 degrees. Back rake varies from 10 to 20, and side rake from 0 to 10 degrees. Reduced back rake may be employed to obtain better chip breakage. The back rake may also be reduced to from 2 to 8 degrees on form tools or other broad tools to prevent chatter.

Parting Tools: For parting tools, the back rake varies from 15 to 20 degrees, the front end relief 8 to 10 degrees, the side relief measured perpendicular to the top face 8 degrees, the side relief measured in the plane of the top face from 3 to 5 degrees.

Milling Magnesium: In general, the coarse-tooth type of cutter is recommended. The number of teeth or cutting blades may be one-third to one-half the number normally used; however, the two-blade fly-cutter has proved to be very satisfactory. As a rule, the land relief or primary peripheral clearance is 10 degrees followed by secondary clearance of 20 degrees. The lands should be narrow, the width being about $\frac{3}{64}$ to $\frac{1}{16}$ inch. The rake, which is positive, is about 15 degrees.

For rough-milling and speeds in feet per minute up to 900 — feed, inch per tooth, 0.005 to 0.025, depth of cut up to 0.5; for speeds 900 to 1500 — feed 0.005 to 0.020, depth of cut up to 0.375; for speeds 1500 to 3000 — feed 0.005 to 0.010, depth of cut up to 0.2.

Drilling Magnesium: If the depth of a hole is less than five times the drill diameter, an ordinary twist drill with highly polished flutes may be used. The included angle of the point may vary from 70 degrees to the usual angle of 118 degrees. The relief angle is about 12 degrees. The drill should be kept sharp and the outer corners rounded to produce a smooth finish and prevent burr formation. For deep hole drilling, use a drill having a helix angle of 40 to 45 degrees with large polished flutes of uniform cross-section throughout the drill length to facilitate the flow of chips. A pyramid-shaped "spur" or "pilot point" at the tip of the drill will reduce the "spiraling or run-off."

Drilling speeds vary from 300 to 2000 feet per minute with feeds per revolution ranging from 0.015 to 0.050 inch.

Reaming Magnesium: Reamers up to 1 inch in diameter should have four flutes; larger sizes, six flutes. These flutes may be either parallel with the axis or have a negative helix angle of 10 degrees. The positive rake angle varies from 5 to 8 degrees, the relief angle from 4 to 7 degrees, and the clearance angle from 15 to 20 degrees.

Tapping Magnesium: Standard taps may be used unless Class 3B tolerances are required, in which case the tap should be designed for use in magnesium. A high-speed steel concentric type with a ground thread is recommended. The concentric form, which eliminates the radial thread relief, prevents jamming of chips while the tap is being backed out of the hole. The positive rake angle at the front may vary from 10 to 25 degrees and the "heel rake angle" at the back of the tooth from 3 to 5 degrees. The chamfer extends over two to three threads. For holes up to $\frac{1}{4}$ inch in diameter, two-fluted taps are recommended; for sizes from $\frac{1}{2}$ to $\frac{3}{4}$ inch, three flutes; and for larger holes, four flutes. Tapping speeds ordinarily range from 75 to 200 feet per minute, and mineral oil cutting fluid should be used.

Threading Dies for Magnesium: Threading dies for use on magnesium should have about the same cutting angles as taps. Narrow lands should be used to provide ample chip space. Either solid or self-opening dies may be used. The latter type is recommended when maximum smoothness is required. Threads may be cut at speeds up to 1000 feet per minute.

Grinding Magnesium: As a general rule, magnesium is ground dry. The highly inflammable dust should be formed into a sludge by means of a spray of water or low-viscosity mineral oil. Accumulations of dust or sludge should be avoided. For surface grinding, when a fine finish is desirable, a low-viscosity mineral oil may be used.

Machining Zinc Alloy Die-Castings.— Machining of zinc alloy die-castings is mostly done without a lubricant. For particular work, especially deep drilling and tapping, a lubricant such as lard oil and kerosene (about half and half) or a 50-50 mixture of kerosene and machine oil may be used to advantage. A mixture of turpentine and kerosene has been found effective on certain difficult jobs.

Reaming: In reaming, tools with six straight flutes are commonly used, although tools with eight flutes irregularly spaced have been found to yield better results by one manufacturer. Many standard reamers have a land that is too wide for best results. A land about 0.015 inch wide is recommended but this may often be ground down to around 0.007 or even 0.005 inch to obtain freer cutting, less tendency to loading, and reduced heating.

Turning: Tools of high-speed steel are commonly employed although the application of Stellite and carbide tools, even on short runs, is feasible. For steel or Stellite, a positive top rake of from 0 to 20 degrees and an end clearance of about 15 degrees are commonly recommended. Where side cutting is involved, a side clearance of about 4 degrees minimum is recommended. With carbide tools, the end clearance should not exceed 6 to 8 degrees and the top rake should be from 5 to 10 degrees positive. For boring, facing, and other lathe operations, rake and clearance angles are about the same as for tools used in turning.

Machining Monel and Nickel Alloys.— These alloys are machined with high-speed steel and with cemented carbide cutting tools. High-speed steel lathe tools usually have a back rake of 6 to 8 degrees, a side rake of 10 to 15 degrees, and relief angles of 8 to 12 degrees. Broad-nose finishing tools have a back rake of 20 to 25 degrees and an end relief angle of 12 to 15 degrees. In most instances, standard commercial cemented-carbide tool holders and tool shanks can be used which provide an acceptable tool geometry. Honing the cutting edge lightly will help if chipping is encountered.

The most satisfactory tool materials for machining Monel and the softer nickel alloys, such as Nickel 200 and Nickel 230, are M2 and T5 for high-speed steel and crater resistant grades of cemented carbides. For the harder nickel alloys such as K Monel, Permanickel, Duranickel, and Nitinol alloys, the recommended tool materials are T15, M41, M42, M43, and for high-speed steel, M42. For carbides, a grade of crater resistant carbide is recommended when the hardness is less than 300 Bhn, and when the hardness is more than 300 Bhn, a grade of straight tungsten carbide will often work best, although some crater resistant grades will also work well.

A sulfurized oil or a water-soluble oil is recommended for rough and finish turning. A sulfurized oil is also recommended for milling, threading, tapping, reaming, and broaching. Recommended cutting speeds for Monel and the softer nickel alloys are 70 to 100 fpm for high-speed steel tools and 200 to 300 fpm for cemented carbide tools. For the harder nickel alloys, the recommended speed for high-speed steel is 40 to 70 fpm for a hardness up to 300 Bhn and for a higher hardness, 10 to 20 fpm; for cemented carbides, 175 to 225 fpm when the hardness is less than 300 Bhn and for a higher hardness, 30 to 70 fpm.

Nickel alloys have a high tendency to work harden. To minimize work hardening caused by machining, the cutting tools should be provided with adequate relief angles and positive rake angles. Furthermore, the cutting edges should be kept sharp and replaced when dull to prevent burnishing of the work surface. The depth of cut and feed should be sufficiently large to ensure that the tool penetrates the work without rubbing.

Machining Copper Alloys.—Copper alloys can be machined by tooling and methods similar to those used for steel, but at higher surface speeds. Machinability is based on a rating of 100 per cent for the free-cutting alloy C35000, which machines with small, easily broken chips. As with steels, copper alloys containing lead have the best machining properties, with alloys containing tin, and lead, having machinability ratings of 80 and 70 per cent. Tellurium and sulphur are added to copper alloys to increase machinability with minimum effect on conductivity. Lead additions are made to facilitate machining, as their effect is to produce easily broken chips.

Copper alloys containing silicon, aluminum, manganese and nickel become progressively more difficult to machine, and produce long, stringy chips, the latter alloys having only 20 per cent of the machinability of the free-cutting alloys. Although copper is frequently machined dry, a cooling compound is recommended. Other lubricants that have been used include tallow for drilling, gasoline for turning, and beeswax for threading.

Machining Hard Rubber.—Tools suitable for steel may be used for hard rubber, with no top or side rake angles and 10 to 20 deg. clearance angles, of high speed steel or tungsten carbide. Without coolant, surface speeds of about 200 ft./min. are recommended for turning, boring and facing, and may be increased to 300 surface ft./min. with coolant.

Drilling of hard rubber requires high speed steel drills of 35 to 40 deg. helix angle to obtain maximum cutting speeds and drill life. Feed rates for drilling range up to 0.015 in./rev. Deep-fluted taps are best for threading hard rubber, and should be 0.002 to 0.005 in. oversize if close tolerances are to be held. Machine oil is used for a lubricant. Hard rubber may be sawn with band saws having 5 to 10 points per inch, running at about 3000 ft./min. or cut with abrasive wheels. Use of coolant in grinding rubber gives a smoother finish.

Piercing and blanking of sheet rubber is best performed with the rubber or dies heated. Straightening of the often-distorted blanks may be carried out by dropping them into a pan of hot water.

Table 1a. Tool Troubleshooting and Practical Tips

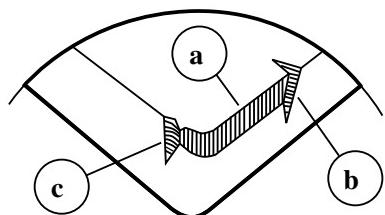
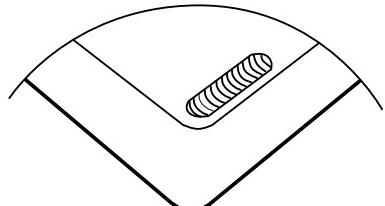
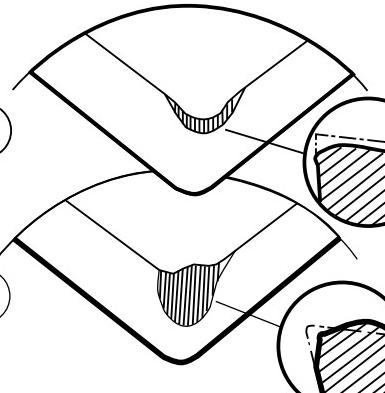
| Problems | Causes | Remedy |
|--|---|--|
|  <p>Flank and notch wear</p> | <p>a. Rapid flank wear causing poor surface finish or out of tolerance.</p> <p>b/c. Notch wear causing poor surface finish and risk of edge breakage.</p> <p>b/c. Oxidation</p> <p>b/c. Attrition</p> <p>c. Oxidation</p> | <p>Reduce the cutting speed. Select a more wear resistant grade.</p> <p>Select Al_2O_3 coated grade. For work hardening materials select a larger lead angle or a more wear resistant grade.</p> <p>Reduce the cutting speed. (When machining heat resistant material with ceramics increase cutting speed.)</p> <p>Select a cermet grade</p> |
|  <p>Crater wear</p> | <p>Excessive crater wear causing a weakened edge. Cutting edge breakthrough on the trailing edge causes poor surface finish.</p> | <p>Diffusion wear due to high cutting temperatures on the rake face.</p> |
|  <p>Plastic deformation</p> | <p>Plastic deformation</p> <p>a—edge depression b—flank impression</p> <p>Leading to poor chip control and poor surface finish. Risk of excessive flank wear leading to insert breakage</p> | <p>Select a more wear resistant grade.</p> <p>a—Reduce speed b—Reduce feed</p> <p>Cutting temperature too high combined with a high pressure.</p> |

Table 1a. (Continued) Tool Troubleshooting and Practical Tips

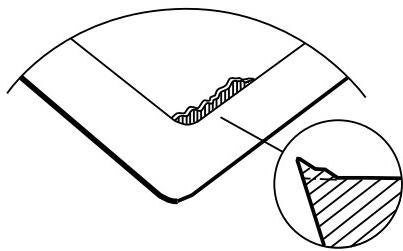
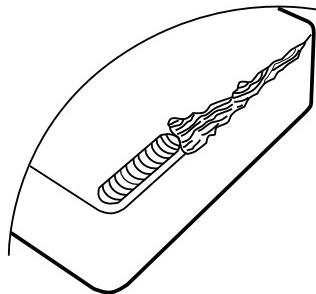
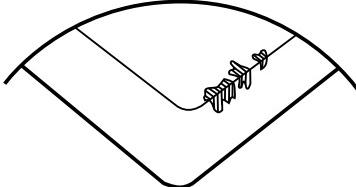
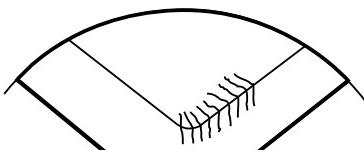
| Problems | Causes | Remedy |
|--|---|---|
|  <p>Built-up edge (B.U.E)</p> | <p>Built-up edge causing poor surface and cutting edge frittering when the B.U.E. is torn away.</p> | <p>Workpiece material is welded to the insert due to: Low cutting speed. Negative cutting geometry.</p> <p>Increase cutting speed. Select a positive geometry.</p> |
|  <p>Chip hammering</p> | <p>The part of the cutting edge not in cut is damaged through chip hammering. Both the top side and the support for the insert can be damaged.</p> | <p>The chips are deflected against the cutting edge.</p> <p>Change the feed. Select an alternative insert geometry.</p> |
|  <p>Frittering</p> | <p>Small cutting edge fractures (frittering) causing poor surface finish and excessive flank wear.</p> | <p>Grade too brittle Insert geometry too weak.</p> <p>Built-up edge</p> <p>Select a tougher grade. Select an insert with a stronger geometry (bigger chamfer for ceramic inserts). Increase cutting speed or select a positive geometry. Reduce feed at beginning of cut.</p> |
|  <p>Thermal crack</p> | <p>Small cracks perpendicular to the cutting edge causing frittering and poor surface finish.</p> <ul style="list-style-type: none"> – Thermal cracks due to temperatures variations caused by: – Intermittent machining – Varying coolant supply. | <p>Select a tougher grade.</p> <ul style="list-style-type: none"> – Turn off coolant or – Flood coolant |

Table 1a. (Continued) Tool Troubleshooting and Practical Tips

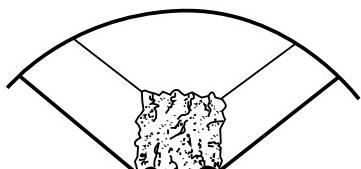
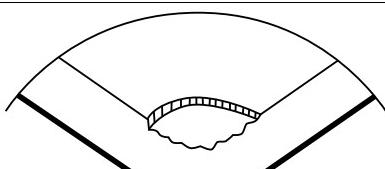
| Problems | Causes | Remedy |
|--|---|---|
|  <p>Insert breakage</p> | Insert breakage that damages not only the insert but also the shim and workpiece. Grade too brittle. Excessive load on the insert. Insert geometry too weak. Insert size too small. | Select a tougher grade. Reduce the feed and / or the depth of cut. Select a stronger geometry, preferably a single sided insert. Select a thicker / larger insert. |
|  <p>Slice fracture—Ceramics</p> | Excessive tool pressure. | Reduce the feed. Select a tougher grade. Select an insert with smaller chamfer. |

Table 1b. Tool Troubleshooting Check List

| Problem | Tool Material | Remedy |
|--|---------------|--|
| Excessive flank wear—Tool life too short | Carbide | 1. Change to harder, more wear-resistant grade 2. Reduce the cutting speed 3. Reduce the cutting speed and increase the feed to maintain production 4. Reduce the feed 5. For work-hardenable materials—increase the feed 6. Increase the lead angle 7. Increase the relief angles |
| | HSS | 1. Use a coolant 2. Reduce the cutting speed 3. Reduce the cutting speed and increase the feed to maintain production 4. Reduce the feed 5. For work-hardenable materials — increase the feed 6. Increase the lead angle 7. Increase the relief angle |
| Excessive cratering | Carbide | 1. Use a crater-resistant grade 2. Use a harder, more wear-resistant grade 3. Reduce the cutting speed 4. Reduce the feed 5. Widen the chip breaker groove |
| | HSS | 1. Use a coolant 2. Reduce the cutting speed 3. Reduce the feed 4. Widen the chip breaker groove |

Table 1b. Tool Troubleshooting Check List

| Problem | Tool Material | Remedy |
|-----------------------------------|-----------------|--|
| Cutting edge chipping | Carbide | <ol style="list-style-type: none"> 1. Increase the cutting speed 2. Lightly hone the cutting edge 3. Change to a tougher grade 4. Use negative-rake tools 5. Increase the lead angle 6. Reduce the feed 7. Reduce the depth of cut 8. Reduce the relief angles 9. If low cutting speed must be used, use a high-additive EP cutting fluid |
| | HSS | <ol style="list-style-type: none"> 1. Use a high additive EP cutting fluid 2. Lightly hone the cutting edge before using 3. Increase the lead angle 4. Reduce the feed 5. Reduce the depth of cut 6. Use a negative rake angle 7. Reduce the relief angles |
| | Carbide and HSS | <ol style="list-style-type: none"> 1. Check the setup for cause if chatter occurs 2. Check the grinding procedure for tool overheating 3. Reduce the tool overhang |
| Cutting edge deformation | Carbide | <ol style="list-style-type: none"> 1. Change to a grade containing more tantalum 2. Reduce the cutting speed 3. Reduce the feed |
| Poor surface finish | Carbide | <ol style="list-style-type: none"> 1. Increase the cutting speed 2. If low cutting speed must be used, use a high additive EP cutting fluid 4. For light cuts, use straight titanium carbide grade 5. Increase the nose radius 6. Reduce the feed 7. Increase the relief angles 8. Use positive rake tools |
| | HSS | <ol style="list-style-type: none"> 1. Use a high additive EP cutting fluid 2. Increase the nose radius 3. Reduce the feed 4. Increase the relief angles 5. Increase the rake angles |
| | Diamond | <ol style="list-style-type: none"> 1. Use diamond tool for soft materials |
| Notching at the depth of cut line | Carbide and HSS | <ol style="list-style-type: none"> 1. Increase the lead angle 2. Reduce the feed |

Table 1c. Common Tool Faults, Failures, and Cures

| Fault Description | Probable Failure | Possible Cure |
|---|--|--|
| Improper Tool Design | | |
| Drastic section changes—widely different thicknesses of adjacent wall sections or protruding elements | In liquid quenching, the thin section will cool and then harden more rapidly than the adjacent thicker section, setting up stresses that may exceed the strength of the steel. | Make such parts of two pieces or use an air-hardening tool steel that avoids the harsh action of a liquid quench. |
| Sharp corners on shoulders or in square holes | Cracking can occur, particularly in liquid quenching, due to stress concentrations. | Apply fillets to the corners and/or use an air-hardening tool steel. |
| Sharp cornered keyways | Failure may arise during service, and is usually considered to be caused by fatigue. | The use of round keyways should be preferred when the general configuration of the part makes it prone to failure due to square keyways. |
| Abrupt section changes in battering tools | Due to impact in service, pneumatic tools are particularly sensitive to stress concentrations that lead to fatigue failures. | Use taper transitions, which are better than even generous fillets. |
| Functional inadequacy of tool design—e.g., insufficient guidance for a punch | Excessive wear or breakage in service may occur. | Assure solid support, avoid unnecessary play, adapt travel length to operational conditions (e.g., punch to penetrate to four-fifths of thickness in hard work material). |
| Improper tool clearance, such as in blanking and punching tools | Deformed and burred parts may be produced, excessive tool wear or breakage can result. | Adapt clearances to material conditions and dimensions to reduce tool load and to obtain clean sheared surfaces. |
| Faulty Condition or Inadequate Grade of Tool Steel | | |
| Improper tool steel grade selection | Typical failures: Chipping—insufficient toughness. Wear—poor abrasion resistance. Softening—inadequate “red hardness.” | Choose the tool steel grade by following recommendations and improve selection when needed, guided by property ratings. |
| Material defects—voids, streaks, tears, flakes, surface cooling cracks, etc. | When not recognized during material inspection, tools made of defective steel often prove to be useless. | Obtain tool steels from reliable sources and inspect tool material for detectable defects. |
| Decarburized surface layer (“bark”) in rolled tool steel bars | Cracking may originate from the decarburized layer or it will not harden (“soft skin”). | Provide allowance for stock to be removed from all surfaces of hot-rolled tool steel. Recommended amounts are listed in tool steel catalogs and vary according to section size, generally about 10 per cent for smaller and 5 per cent for larger diameters. |
| Brittleness caused by poor carbide distribution in high-alloy tool steels | Excessive brittleness can cause chipping or breakage during service. | Bars with large diameter (above about 4 inches) tend to be prone to nonuniform carbide distribution. Choose upset forged discs instead of large-diameter bars. |

Table 1c. Common Tool Faults, Failures, and Cures

| Fault Description | Probable Failure | Possible Cure |
|---|--|--|
| <i>(Continued)</i> Faulty Condition or Inadequate Grade of Tool Steel | | |
| Unfavorable grain flow | Improper grain flow of the steel used for milling cutters and similar tools can cause teeth to break out. | Upset forged discs made with an upset ratio of about 2 to 1 (starting to upset thickness) display radial grain flow. Highly stressed tools, such as gear-shaper cutters, may require the cross forging of blanks. |
| Heat-Treatment Faults | | |
| Improper preparation for heat treatment. Certain tools may require stress relieving or annealing, and often preheating, too | Tools highly stressed during machining or forming, unless stress relieved, may aggravate the thermal stresses of heat treatment, thus causing cracks. Excessive temperature gradients developed in nonpreheated tools with different section thicknesses can cause warpage. | Stress relieve, when needed, before hardening. Anneal prior to heavy machining or cold forming (e.g., hobbing). Preheat tools (a) having substantial section thickness variations or (b) requiring high quenching temperatures, as those made of high-speed tool steels. |
| Overheating during hardening; quenching from too high a temperature | Causes grain coarsening and a sensitivity to cracking that is more pronounced in tools with drastic section changes. | Overheated tools have a characteristic microstructure that aids recognition of the cause of failure and indicates the need for improved temperature control. |
| Low hardening temperature | The tool may not harden at all, or in its outer portion only, thereby setting up stresses that can lead to cracks. | Controlling both the temperature of the furnace and the time of holding the tool at quenching temperature will prevent this not too frequent deficiency. |
| Inadequate composition or condition of the quenching media | Water-hardening tool steels are particularly sensitive to inadequate quenching media, which can cause soft spots or even violent cracking. | For water-hardening tool steels, use water free of dissolved air and contaminants, also assure sufficient quantity and proper agitation of the quench. |
| Improper handling during and after quenching | Cracking, particularly of tools with sharp corners, during the heat treatment can result from holding the part too long in the quench or incorrectly applied tempering. | Following the steel producer's specifications is a safe way to assure proper heat-treatment handling. In general, the tool should be left in the quench until it reaches a temperature of 150 to 200°F, and should then be transferred promptly into a warm tempering furnace. |
| Insufficient tempering | Omission of double tempering for steel types that require it may cause early failure by heat checking in hot-work steels or make the tool abnormally sensitive to grinding checks. | Double temper highly alloyed tool steel of the high-speed, hot-work, and high-chromium categories, to remove stresses caused by martensite formed during the first tempering phase. Second temper also increases hardness of most high-speed steels. |

Table 1c. Common Tool Faults, Failures, and Cures

| Fault Description | Probable Failure | Possible Cure |
|---|--|---|
| Decarburization and carburization | Unless hardened in a neutral atmosphere the original carbon content of the tool surface may be changed: Reduced carbon (decarburization) causes a soft layer that wears rapidly. Increased carbon (carburization) when excessive may cause brittleness. | Heating in neutral atmosphere or well-maintained salt bath and controlling the furnace temperature and the time during which the tool is subjected to heating can usually keep the carbon imbalance within acceptable limits. |
| Grinding Damages | | |
| Excessive stock removal rate causing heating of the part surface beyond the applied tempering temperature | Scorched tool surface displaying temper colors varying from yellow to purple, depending on the degree of heat, causes softening of the ground surface. When coolant is used, a local rehardening can take place, often resulting in cracks. | Prevention: by reducing speed and feed, or using coarser, softer, more openstructured grinding wheel, with ample coolant. Correction: eliminate the discolored layer by subsequent light stock removal. Not always a cure, because the effects of abusive grinding may not be corrected. |
| Improper grinding wheel specifications; grain too fine or bond too hard | Intense localized heating during grinding may set up surface stresses causing grinding cracks. These cracks are either parallel but at right angles to the direction of grinding or, when more advanced, form a network. May need cold etch or magnetic particle testing to become recognizable. | Prevention: by correcting the grinding wheel specifications. Correction: in shallow (0.002- to 0.004-inch) cracks, by removing the damaged layer, when permitted by the design of the tool, using very light grinding passes. |
| Incorrectly dressed or loaded grinding wheel | Heating of the work surface can cause scorching or cracking. Incorrect dressing can also cause a poor finish of the ground work surface. | Dress wheel with sharper diamond and faster diamond advance to produce coarser wheel surface. Alternate dressing methods, like crush-dressing, can improve wheel surface conditions. Dress wheel regularly to avoid loading or glazing of the wheel surface. |
| Inadequate coolant, with regard to composition, amount, distribution, and cleanliness | Introducing into the tool surface heat that is not adequately dissipated or absorbed by the coolant can cause softening, or even the development of cracks. | Improve coolant supply and quality, or reduce stock removal rate to reduce generation of heat in grinding. |
| Damage caused by abusive abrasive cutoff | The intensive heat developed during this process can cause a hardening of the steel surface, or may even result in cracks. | Reduce rate of advance; adopt wheel specifications better suited for the job. Use ample coolant or, when harmful effect not eliminated, replace abrasive cutoff by some cooler-acting stock separation method (e.g., sawing or lathe cutoff) unless damaged surface is being removed by subsequent machining. |

Note: Illustrated examples of tool failures from causes such as listed above may be found in "The Tool Steel Trouble Shooter" handbook, published by Bethlehem Steel Corporation.

COMPUTER NUMERICAL CONTROL

Format Classification.— The *format classification sheet* completely describes the format requirements of a control system and gives other important information required to program a particular control including: the type of machine, the format classification shorthand and format detail, a listing of specific letter address codes recognized by the system (for example, G-codes: G01, G02, G17, etc.) and the range of values the available codes may take (S range: 10 to 1800 rpm, for example), an explanation of any codes not specifically assigned by the Standard, and any other unique features of the system.

The *format classification shorthand* is a nine- or ten-digit code that gives the type of system, the number of motion and other words available, the type and format of dimensional data required by the system, the number of motion control channels, and the number of numerically controlled axes of the system. The *format detail* very succinctly summarizes details of the machine and control system. This NC shorthand gives the letter address words and word lengths that can be used to make up a block. The format detail defines the basic features of the control system and the type of machine tool to which it refers. For example, the format detail

N4G2X + 24Y + 24Z + 24B24I24J24F31T4M2

specifies that the NC machine is a machining center (has X-, Y-, and Z-axes) and a tool changer with a four-digit tool selection code (T4); the three linear axes are programmed with two digits before the decimal point and four after the decimal point (X + 24Y + 24Z + 24) and can be positive or negative; probably has a horizontal spindle and rotary table (B24 = rotary motion about the Y-axis); has circular interpolation (I24J24); has a feed rate range in which there are three digits before and one after the decimal point (F31); and can handle a four-digit sequence number (N4), two-digit G-words (G2), and two-digit miscellaneous words (M2). The sequence of letter addresses in the format detail is also the sequence in which words with those addresses should appear when used in a block.

The information given in the format shorthand and format detail is especially useful when programs written for one machine are to be used on different machines. Programs that use the variable block data format described in RS-274-D can be used interchangeably on systems that have the same format classification, but for complete program compatibility between machines, other features of the machine and control system must also be compatible, such as the relationships of the axes and the availability of features and control functions.

Control systems differ in the way that the numbers may be written. Most newer CNC machines accept numbers written in a decimal-point format, however, some systems require numbers to be in a fixed-length format that does not use an explicit decimal point. In the latter case, the control system evaluates a number based on the number of digits it has, including zeros. *Zero suppression* in a control system is an arrangement that allows zeros before the first significant figure to be dropped (leading zero suppression) or allows zeros after the last significant figure to be dropped (trailing zero suppression). An X-axis movement of 05.3400, for example, could be expressed as 053400 if represented in the full field format, 53400 (leading zero suppression), or 0534 (trailing zero suppression). With decimal-point programming, the above number is expressed simply as 5.34. To ensure program compatibility between machines, all leading and trailing zeros should be included in numbers unless decimal-point programming is used.

Table 1. G-Code Addresses

| Code | | Description | Code | | Description |
|---------------------------------|-----|---|-------------------------------|-----|---|
| G00 | abc | Rapid traverse, point to point (M,L) | G34 | abc | Thread cutting, increasing lead (L) |
| G01 | abc | Linear interpolation (M,L) | G35 | abc | Thread cutting, decreasing lead (L) |
| G02 | abc | Circular interpolation — clockwise movement (M,L) | G36-G39 | ab | Permanently unassigned |
| G03 | abc | Circular interpolation—counterclockwise movement (M,L) | G36 | c | Used for automatic acceleration and deceleration when the blocks are short (M,L) |
| G04 | ab | Dwell—a programmed time delay (M,L) | G37, G37.1, G37.2, G37.3G37.4 | | Used for tool gaging (M,L) |
| G05 | ab | Unassigned | G38 | | Used for probing to measure the diameter and center of a hole (M) |
| G06 | abc | Parabolic interpolation (M,L) | G38.1 | | Used with a probe to measure the parallelness of a part with respect to an axis (M) |
| G07 | c | Used for programming with cylindrical diameter values (L) | G39, G39.1 | | Generates a nonprogrammed block to improve cycle time and corner cutting quality when used with cutter compensation (M) |
| G08 | ab | Programmed acceleration (M,L). ^d Also for lathe programming with cylindrical diameter values | G39 | | Tool tip radius compensation used with linear generated block (L) |
| G09 | ab | Programmed deceleration (M,L). ^d Used to stop the axis movement at a precise location (M,L) | G39.1 | | Tool tip radius compensation used with circular generated block (L) |
| G10–G12 | ab | Unassigned. ^d Sometimes used for machine lock and unlock devices | G40 | abc | Cancel cutter compensation/offset (M) |
| G13–G16 | ac | Axis selection (M,L) | G41 | abc | Cutter compensation, left (M) |
| G13–G16 | b | Unassigned | G42 | abc | Cutter compensation, right (M) |
| G13 | | Used for computing lines and circle intersections (M,L) | G43 | abc | Cutter offset, inside corner (M,L) |
| G14, G14.1 | c | Used for scaling (M,L) | G44 | abc | Cutter offset, outside corner (M,L) |
| G15–G16 | c | Polar coordinate programming (M) | G45–G49 | ab | Unassigned |
| G15, G16.1 | c | Cylindrical interpolation—C axis (L) | G50–G59 | a | Reserved for adaptive control (M,L) |
| G16.2 | c | End face milling—C axis (L) | G50 | bb | Unassigned |
| G17–G19 | abc | X-Y, X-Z, Y-Z plane selection, respectively (M,L) | G50.1 | c | Cancel mirror image (M,L) |
| G20 | | Unassigned | G51.1 | c | Program mirror image (M,L) |
| G22–G32 | ab | Unassigned | G52 | b | Unassigned |
| G22–G23 | c | Defines safety zones in which the machine axis may not enter (M,L) | G52 | | Used to offset the axes with respect to the coordinate zero point (see G92) (M,L) |
| G22.1, G233.1 | c | Defines safety zones in which the cutting tool may not exit (M,L) | G53 | bc | Datum shift cancel |
| G24 | c | Single-pass rough-facing cycle (L) | G53 | c | Call for motion in the machine coordinate system (M,L) |
| G27–G29 | | Used for automatically moving to and returning from home position (M,L) | G54–G59 | bc | Datum shifts (M,L) |
| G30 | | Return to an alternate home position (M,L) | G54–G59.3 | c | Allows for presetting of work coordinate systems (M,L) |
| G31, G31.1, G31.2, G31.3, G31.4 | | External skip function, moves an axis on a linear path until an external signal aborts the move (M,L) | G61 | c | Modal equivalent of G09 except that rapid moves are not taken to a complete stop before the next motion block is executed (M,L) |
| G33 | abc | Thread cutting, constant lead (L) | G60–G62 | abc | Unassigned |

Table 1. G-Code Addresses

| Code | | Description | Code | | Description |
|---------|-----|---|--------|-----|--|
| G62 | c | Automatic corner override, reduces the feed rate on an inside corner cut (M,L) | G80 | abc | Cancel fixed cycles |
| G63 | a | Unassigned | G81 | abc | Drill cycle, no dwell and rapid out (M,L) |
| G63 | bc | Tapping mode (M,L) | G82 | abc | Drill cycle, dwell and rapid out (M,L) |
| G64–G69 | abc | Unassigned | G83 | abc | Deep hole peck drilling cycle (M,L) |
| G64 | c | Cutting mode, usually set by the system installer (M,L) | G84 | abc | Right-hand tapping cycle (M,L) |
| G65 | c | Calls for a parametric macro (M,L) | G84.1 | c | Left-hand tapping cycle (M,L) |
| G66 | c | Calls for a parametric macro. Applies to motion blocks only (M,L) | G85 | abc | Boring cycle, no dwell, feed out (M,L) |
| G66.1 | c | Same as G66 but applies to all blocks (M,L) | G86 | abc | Boring cycle, spindle stop, rapid out (M,L) |
| G67 | c | Stop the modal parametric macro (see G65, G66, G66.1) (M,L) | G87 | abc | Boring cycle, manual retraction (M,L) |
| G68 | c | Rotates the coordinate system (i.e., the axes) (M) | G88 | abc | Boring cycle, spindle stop, manual retraction (M,L) |
| G69 | c | Cancel axes rotation (M) | G88.1 | | Pocket milling (rectangular and circular), roughing cycle (M) |
| G70 | abc | Inch programming (M,L) | G88.2 | | Pocket milling (rectangular and circular), finish cycle (M) |
| G71 | abc | Metric programming (M,L) | G88.3 | | Post milling, roughs out material around a specified area (M) |
| G72 | ac | Circular interpolation CW (three-dimensional) (M) | G88.4 | | Post milling, finish cuts material around a post (M) |
| G72 | b | Unassigned | G88.5 | | Hemisphere milling, roughing cycle (M) |
| G72 | c | Used to perform the finish cut on a turned part along the Z-axis after the roughing cuts initiated under G73, G74, or G75 codes (L) | G88.6 | | Hemisphere milling, finishing cycle (M) |
| G73 | b | Unassigned | G89 | abc | Boring cycle, dwell and feed out (M,L) |
| G73 | c | Deep hole peck drilling cycle (M); OD and ID roughing cycle, running parallel to the Z-axis (L) | G89.1 | | Irregular pocket milling, roughing cycle (M) |
| G73 | c | Deep hole peck drilling cycle (M); OD and ID roughing cycle, running parallel to the Z-axis (L) | G89.2 | | Irregular pocket milling, finishing cycle (M) |
| G74 | ac | Cancel multiquadrant circular interpolation (M,L) | G90 | abc | Absolute dimension input (M,L) |
| G74 | bc | Move to home position (M,L) | G91 | abc | Incremental dimension input (M,L) |
| G74 | c | Left-hand tapping cycle (M) | G92 | abc | Preload registers, used to shift the coordinate axes relative to the current tool position (M,L) |
| G74 | | Rough facing cycle (L) | G93 | abc | Inverse time feed rate (velocity / distance) (M,L) |
| G75 | ac | Multiquadrant circular interpolation (M,L) | G94 | c | Feed rate in inches or millimeters per minute (ipm or mpm) (M,L) |
| G75 | b | Unassigned | G95 | abc | Feed rate given directly in inches or millimeters per revolution (ipr or mpr) (M,L) |
| G75 | | Roughing routine for castings or forgings (L) | G96 | abc | Maintains a constant surface speed, feet (meters) per minute (L) |
| G76–G79 | ab | Unassigned | G97 | abc | Spindle speed programmed in rpm (M,L) |
| | | | G98–99 | ab | Unassigned |

^a Adheres to ANSI/EIA RS-274-D;

^b Adheres to ISO 6983/1,2,3 Standards; where both symbols appear together, the ANSI/EIA and ISO standard codes are comparable;

^c This code is modal. All codes that are not identified as modal are non-modal, when used according to the corresponding definition.

^d Indicates a use of the code that does not conform with the Standard.

Symbols following a description: (M) indicates that the code applies to a mill or machining center; (L) indicates that the code applies to turning machines; (M,L) indicates that the code applies to both milling and turning machines.

Codes that appear more than once in the table are codes that are in common use, but are not defined by the Standard or are used in a manner that is different than that designated by the Standard (e.g., see G61).

Table 2. Letter Addresses Used in Numerical Control

| Letter Address | Description | Refers to |
|----------------|--|--------------------------------------|
| A | Angular dimension about the X-axis, measured in decimal parts of a degree | Axis nomenclature |
| B | Angular dimension about the Y-axis, measured in decimal parts of a degree | Axis nomenclature |
| C | Angular dimension about the Z-axis, measured in decimal parts of a degree | Axis nomenclature |
| D | Angular dimension about a special axis, or third feed function, or tool function for selection of tool compensation | Axis nomenclature |
| E | Angular dimension about a special axis or second feed function | Axis nomenclature |
| F | Feed word (code) | Feed words |
| G | Preparatory word (code) | Preparatory words |
| H | Unassigned | |
| I | Interpolation parameter or thread lead parallel to the X-axis | Circular interpolation and threading |
| J | Interpolation parameter or thread lead parallel to the Y-axis | Circular interpolation and threading |
| K | Interpolation parameter or thread lead parallel to the Z-axis | Circular interpolation and threading |
| L | Unassigned | |
| M | Miscellaneous or auxilliary function | Miscellaneous functions |
| N | Sequence number | Sequence number |
| O | Sequence number for secondary head only | Sequence number |
| P | Third rapid-traverse dimension or tertiary-motion dimension parallel to X | Axis nomenclature |
| Q | Second rapid-traverse dimension or tertiary-motion dimension parallel to Y | Axis nomenclature |
| R | First rapid-traverse dimension or tertiary-motion dimension parallel to Z or radius for constant surface-speed calculation | Axis nomenclature |
| S | Spindle-speed function | Spindle speed |
| T | Tool function | Tool function |
| U | Secondary-motion dimension parallel to X | Axis nomenclature |
| V | Secondary-motion dimension parallel to Y | Axis nomenclature |
| W | Secondary-motion dimension parallel to Z | Axis nomenclature |
| X | Primary X-motion dimension | Axis nomenclature |
| Y | Primary Y-motion dimension | Axis nomenclature |
| Z | Primary Z-motion dimension | Axis nomenclature |

Miscellaneous Functions (M-Words).—Miscellaneous functions, or M-codes also referred to as auxiliary functions, constitute on-off type commands. M functions are used to control actions such as starting and stopping of motors, turning coolant on and off, changing tools, and clamping and unclamping parts. M functions are made up of the letter M followed by a two-digit code.

Table 3. Miscellaneous Function Words from EIA Standard RS-274-D

| Code | Description |
|------------|--|
| M00 | Automatically <i>stops</i> the machine. The operator must push a button to continue with the remainder of the program. |
| M01 | An <i>optional stop</i> acted upon only when the operator has previously signaled for this command by pushing a button. The machine will automatically stop when the control system senses the M01 code. |
| M02 | This <i>end-of-program</i> code stops the machine when all commands in the block are completed. May include rewinding of tape. |
| M03 | Start <i>spindle rotation</i> in a <i>clockwise</i> direction—looking out from the spindle face. |
| M04 | Start <i>spindle rotation</i> in a <i>counterclockwise</i> direction—looking out from the spindle face. |
| M05 | <i>Stop</i> the spindle in a normal and efficient manner. |
| M06 | Command to <i>change a tool</i> (or tools) manually or automatically. Does not cover tool selection, as is possible with the T-words. |
| M07 to M08 | M07 (coolant 2) and M08 (coolant 1) are codes to <i>turn on coolant</i> . M07 may control <i>flood</i> coolant and M08 <i>mist</i> coolant. |
| M09 | Shuts off the coolant. |
| M10 to M11 | M10 applies to automatic <i>clamping</i> of the machine slides, workpiece, fixture spindle, etc. M11 is an unclamping code. |
| M12 | An inhibiting code used to synchronize multiple sets of axes, such as a four-axis lathe having two independently operated heads (turrets). |
| M13 | Starts <i>CW spindle</i> motion and <i>coolant on</i> in the same command. |
| M14 | Starts <i>CCW spindle</i> motion and <i>coolant on</i> in the same command. |
| M15 to M16 | Rapid traverse of feed motion in either the +(M15) or -(M16) direction. |
| M17 to M18 | Unassigned. |
| M19 | Oriented spindle stop. Causes the spindle to stop at a predetermined angular position. |
| M20 to M29 | Permanently unassigned. |
| M30 | An <i>end-of-tape</i> code similar to M02, but M30 will also rewind the tape; also may switch automatically to a second tape reader. |
| M31 | A command known as <i>interlock bypass</i> for temporarily circumventing a normally provided interlock. |
| M32 to M35 | Unassigned. |
| M36 to M39 | Permanently unassigned. |
| M40 to M46 | Used to signal gear changes if required at the machine; otherwise, unassigned. |
| M47 | Continues program execution from the start of the program unless inhibited by an interlock signal. |
| M48 to M49 | M49 deactivates a manual spindle or feed override and returns the parameter to the programmed value; M48 cancels M49. |
| M50 to M57 | Unassigned. |
| M58 to M59 | Holds the rpm constant at the value in use when M59 is initiated; M58 cancels M59. |
| M60 to M89 | Unassigned. |
| M90 to M99 | Reserved for use by the machine user. |

GRINDING WHEELS

Safety in Operating Grinding Wheels.— Grinding wheels, are prone to damage caused by improper handling and operation. Vitrified wheels, comprising the major part of grinding wheels used in industry, are held together by an inorganic bond which is actually a type of pottery product and therefore brittle and breakable.

It must also be understood that during the grinding process very substantial forces act on the grinding wheel, including the centrifugal force due to rotation, the grinding forces resulting from the resistance of the work material, and shocks caused by sudden contact with the work. To be able to resist these forces, the grinding wheel must have a substantial minimum strength throughout that is well beyond that needed to hold the wheel together under static conditions.

A damaged grinding wheel can disintegrate during grinding, which normally are constrained thus presenting great hazards to both operator and equipment. Safeguards have been formulated into rules and regulations and are set forth in the ANSI B7.1-1988, entitled the American National Standard Safety Requirements for the Use, Care, and Protection of Abrasive Wheels. All operators should be familiar with the rules.

Handling, Storage and Inspection.— Grinding wheels should be hand carried, or transported, with proper support. A grinding wheel must not be rolled around on its periphery. The storage area, positioned near the grinding machines, should be free from excessive temperature variations and humidity. Specially built racks are recommended on which the smaller or thin wheels are stacked lying on their sides and the larger wheels in an upright position on two-point cradle supports consisting of appropriately spaced wooden bars. Partitions should separate either the individual wheels, or a small group of identical wheels. Good accessibility to the stored wheels reduces the need of undesirable handling.

Inspection will primarily be directed at detecting visible damage, mostly originating from handling and shipping. Cracks that are not obvious can usually be detected by "ring testing," which consists of suspending the wheel from its hole and tapping it with a non-metallic implement. Heavy wheels may be allowed to rest vertically on a clean, hard floor while performing this test. A clear metallic tone, a "ring," should be heard; a dead sound being indicative of a possible crack or cracks in the wheel.

Machine Conditions.— The general design of grinding machines must ensure safe operation under normal conditions. The bearings and grinding wheel spindle must be dimensioned to withstand the expected forces and ample driving power should be provided to ensure maintenance of the rated spindle speed. For the protection of the operator, stationary machines used for dry grinding should have provision made for connection to an exhaust system and when used for off-hand grinding, a work support must be available.

Wheel guards are particularly important protection elements and their material specifications, wall thicknesses, and construction principles should agree with the Standard's specifications. The exposure of the wheel should be just enough to avoid interference with the grinding operation. The need for access of the work to the grinding wheel will define the boundary of guard opening, particularly in the direction of the operator.

Grinding Wheel Mounting.— The mass and speed of the operating grinding wheel makes it particularly sensitive to imbalance. Vibrations that result from such conditions are harmful to the machine, particularly the spindle bearings, and they also affect the ground surface, i.e., wheel imbalance causes chatter marks and interferes with size control. Grinding wheels are shipped from the manufacturer's plant in a balanced condition, but retaining the balanced state after mounting the wheel is quite uncertain. Balancing of the mounted wheel is thus required, and is particularly important for medium and large size wheels, as well as for producing accurate and smooth surfaces. The most common way of balancing mounted wheels is by using balancing flanges with adjustable weights. The

wheel and balancing flanges are mounted on a short balancing arbor, the two concentric and round stub ends of which are supported in a balancing stand.

Such stands are of two types: 1) the parallel straight-edged, which must be set up precisely level; and 2) the disk type having two pairs of ball bearing mounted overlapping disks, which form a V for containing the arbor ends without hindering the free rotation of the wheel mounted on that arbor.

The wheel will then rotate only when it is out of balance and its heavy spot is not in the lowest position. Rotating the wheel by hand to different positions will move the heavy spot, should such exist, from the bottom to a higher location where it can reveal its presence by causing the wheel to turn. Having detected the presence and location of the heavy spot, its effect can be cancelled by displacing the weights in the circular groove of the flange until a balanced condition is accomplished.

Flanges are commonly used means for holding grinding wheels on the machine spindle. For that purpose, the wheel can either be mounted directly through its hole or by means of a sleeve which slips over a tapered section of the machine spindle. Either way, the flanges must be of equal diameter, usually not less than one-third of the new wheel's diameter. The purpose is to securely hold the wheel between the flanges without interfering with the grinding operation even when the wheel becomes worn down to the point where it is ready to be discarded. Blotters or flange facings of compressible material should cover the entire contact area of the flanges.

One of the flanges is usually fixed while the other is loose and can be removed and adjusted along the machine spindle. The movable flange is held against the mounted grinding wheel by means of a nut engaging a threaded section of the machine spindle. The sense of that thread should be such that the nut will tend to tighten as the spindle revolves. In other words, to remove the nut, it must be turned in the direction that the spindle revolves when the wheel is in operation.

Safe Operating Speeds.— Safe grinding processes are predicated on the proper use of the previously discussed equipment and procedures, and are greatly dependent on the application of adequate operating speeds. The Standard establishes maximum speeds at which grinding wheels can be operated, assigning the various types of wheels to several classification groups. Different values are listed according to bond type and to wheel strength, distinguishing between low, medium and high strength wheels.

For the purpose of general information, the accompanying table shows an abbreviated version of the Standard's specification. The maximum operating speeds indicated on the wheel's tag must never be exceeded. All grinding wheels of 6 inches or greater diameter must be test run in the wheel manufacturer's plant at a speed that for all wheels having operating speeds in excess of 5000 sfpm is 1.5 times the maximum speed marked on the tag of the wheel.

The table shows the permissible wheel speeds in surface feet per minute (sfpm) units, whereas the tags on the grinding wheels state, for the convenience of the user, the maximum operating speed in revolutions per minute (rpm). The sfpm unit has the advantage of remaining valid for worn wheels whose rotational speed may be increased to the applicable sfpm value. The conversion from either one to the other of these two kinds of units is a matter of simple calculation using the formulas:

$$\text{sfpm} = \text{rpm} \times \frac{D}{12} \times \pi \quad \text{or} \quad \text{rpm} = \frac{\text{sfpm} \times 12}{D \times \pi}$$

Where D = maximum diameter of the grinding wheel, in inches. Table 1, showing the conversion values from surface speed into rotational speed, can be used for the direct reading of the rpm values corresponding to several different wheel diameters and surface speeds.

Table 1. Revolutions Per Minute for Various Grinding Speeds and Wheel Diameters Based on ANSI B7.1-1988

| Wheel Diameter, Inch | Peripheral (Surface) Speed, Feet per Minute | | | | | | | | | | | | | | | | Wheel Diameter, Inch |
|----------------------|---|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------------------|
| | 4,000 | 4,500 | 5,000 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 8,500 | 9,000 | 9,500 | 10,000 | 12,000 | 14,000 | 16,000 | |
| | Revolutions per Minute | | | | | | | | | | | | | | | | |
| 1 | 15,279 | 17,189 | 19,099 | 21,008 | 22,918 | 24,828 | 26,738 | 28,648 | 30,558 | 32,468 | 34,377 | 36,287 | 38,197 | 45,837 | 53,476 | 61,115 | 1 |
| 2 | 7,639 | 8,594 | 9,549 | 10,504 | 11,459 | 12,414 | 13,369 | 14,324 | 15,279 | 16,234 | 17,189 | 18,144 | 19,099 | 22,918 | 26,738 | 30,558 | 2 |
| 3 | 5,093 | 5,730 | 6,366 | 7,003 | 7,639 | 8,276 | 8,913 | 9,549 | 10,186 | 10,823 | 11,459 | 12,096 | 12,732 | 15,279 | 17,825 | 20,372 | 3 |
| 4 | 3,820 | 4,297 | 4,775 | 5,252 | 5,730 | 6,207 | 6,685 | 7,162 | 7,639 | 8,117 | 8,594 | 9,072 | 9,549 | 11,459 | 13,369 | 15,279 | 4 |
| 5 | 3,056 | 3,438 | 3,820 | 4,202 | 4,584 | 4,966 | 5,348 | 5,730 | 6,112 | 6,494 | 6,875 | 7,257 | 7,639 | 9,167 | 10,695 | 12,223 | 5 |
| 6 | 2,546 | 2,865 | 3,183 | 3,501 | 3,820 | 4,138 | 4,456 | 4,775 | 5,093 | 5,411 | 5,730 | 6,048 | 6,366 | 7,639 | 8,913 | 10,186 | 6 |
| 7 | 2,183 | 2,456 | 2,728 | 3,001 | 3,274 | 3,547 | 3,820 | 4,093 | 4,365 | 4,638 | 4,911 | 5,184 | 5,457 | 6,548 | 7,639 | 8,731 | 7 |
| 8 | 1,910 | 2,149 | 2,387 | 2,626 | 2,865 | 3,104 | 3,342 | 3,581 | 3,820 | 4,058 | 4,297 | 4,536 | 4,775 | 5,730 | 6,685 | 7,639 | 8 |
| 9 | 1,698 | 1,910 | 2,122 | 2,334 | 2,546 | 2,759 | 2,971 | 3,183 | 3,395 | 3,608 | 3,820 | 4,032 | 4,244 | 5,093 | 5,942 | 6,791 | 9 |
| 10 | 1,528 | 1,719 | 1,910 | 2,101 | 2,292 | 2,483 | 2,674 | 2,865 | 3,056 | 3,247 | 3,438 | 3,629 | 3,820 | 4,584 | 5,348 | 6,112 | 10 |
| 12 | 1,273 | 1,432 | 1,592 | 1,751 | 1,910 | 2,069 | 2,228 | 2,387 | 2,546 | 2,706 | 2,865 | 3,024 | 3,183 | 3,820 | 4,456 | 5,093 | 12 |
| 14 | 1,091 | 1,228 | 1,364 | 1,501 | 1,637 | 1,773 | 1,910 | 2,046 | 2,183 | 2,319 | 2,456 | 2,592 | 2,728 | 3,274 | 3,820 | 4,365 | 14 |
| 16 | 955 | 1,074 | 1,194 | 1,313 | 1,432 | 1,552 | 1,671 | 1,790 | 1,910 | 2,029 | 2,149 | 2,268 | 2,387 | 2,865 | 3,342 | 3,820 | 16 |
| 18 | 849 | 955 | 1,061 | 1,167 | 1,273 | 1,379 | 1,485 | 1,592 | 1,698 | 1,804 | 1,910 | 2,016 | 2,122 | 2,546 | 2,971 | 3,395 | 18 |
| 20 | 764 | 859 | 955 | 1,050 | 1,146 | 1,241 | 1,337 | 1,432 | 1,528 | 1,623 | 1,719 | 1,814 | 1,910 | 2,292 | 2,674 | 3,056 | 20 |
| 22 | 694 | 781 | 868 | 955 | 1,042 | 1,129 | 1,215 | 1,302 | 1,389 | 1,476 | 1,563 | 1,649 | 1,736 | 2,083 | 2,431 | 2,778 | 22 |
| 24 | 637 | 716 | 796 | 875 | 955 | 1,035 | 1,114 | 1,194 | 1,273 | 1,353 | 1,432 | 1,512 | 1,592 | 1,910 | 2,228 | 2,546 | 24 |
| 26 | 588 | 661 | 735 | 808 | 881 | 955 | 1,028 | 1,102 | 1,175 | 1,249 | 1,322 | 1,396 | 1,469 | 1,763 | 2,057 | 2,351 | 26 |
| 28 | 546 | 614 | 682 | 750 | 819 | 887 | 955 | 1,023 | 1,091 | 1,160 | 1,228 | 1,296 | 1,364 | 1,637 | 1,910 | 2,183 | 28 |
| 30 | 509 | 573 | 637 | 700 | 764 | 828 | 891 | 955 | 1,019 | 1,082 | 1,146 | 1,210 | 1,273 | 1,528 | 1,783 | 2,037 | 30 |
| 32 | 477 | 537 | 597 | 657 | 716 | 776 | 836 | 895 | 955 | 1,015 | 1,074 | 1,134 | 1,194 | 1,432 | 1,671 | 1,910 | 32 |
| 34 | 449 | 506 | 562 | 618 | 674 | 730 | 786 | 843 | 899 | 955 | 1,011 | 1,067 | 1,123 | 1,348 | 1,573 | 1,798 | 34 |
| 36 | 424 | 477 | 531 | 584 | 637 | 690 | 743 | 796 | 849 | 902 | 955 | 1,008 | 1,061 | 1,273 | 1,485 | 1,698 | 36 |
| 38 | 402 | 452 | 503 | 553 | 603 | 653 | 704 | 754 | 804 | 854 | 905 | 955 | 1,005 | 1,206 | 1,407 | 1,608 | 38 |
| 40 | 382 | 430 | 477 | 525 | 573 | 621 | 668 | 716 | 764 | 812 | 859 | 907 | 955 | 1,146 | 1,337 | 1,528 | 40 |
| 42 | 364 | 409 | 455 | 500 | 546 | 591 | 637 | 682 | 728 | 773 | 819 | 864 | 909 | 1,091 | 1,273 | 1,455 | 42 |
| 44 | 347 | 391 | 434 | 477 | 521 | 564 | 608 | 651 | 694 | 738 | 781 | 825 | 868 | 1,042 | 1,215 | 1,389 | 44 |
| 46 | 332 | 374 | 415 | 457 | 498 | 540 | 581 | 623 | 664 | 706 | 747 | 789 | 830 | 996 | 1,163 | 1,329 | 46 |
| 48 | 318 | 358 | 398 | 438 | 477 | 517 | 557 | 597 | 637 | 676 | 716 | 756 | 796 | 955 | 1,114 | 1,273 | 48 |
| 53 | 288 | 324 | 360 | 396 | 432 | 468 | 504 | 541 | 577 | 613 | 649 | 685 | 721 | 865 | 1,009 | 1,153 | 53 |
| 60 | 255 | 286 | 318 | 350 | 382 | 414 | 446 | 477 | 509 | 541 | 573 | 605 | 637 | 764 | 891 | 1,019 | 60 |
| 72 | 212 | 239 | 265 | 292 | 318 | 345 | 371 | 398 | 424 | 451 | 477 | 504 | 531 | 637 | 743 | 849 | 72 |

Portable Grinders.— The above discussed rules and regulations, devised primarily for stationary grinding machines apply also to portable grinders. In addition, the details of various other regulations, specially applicable to different types of portable grinders are discussed in the Standard, which should be consulted, particularly for safe applications of portable grinding machines.

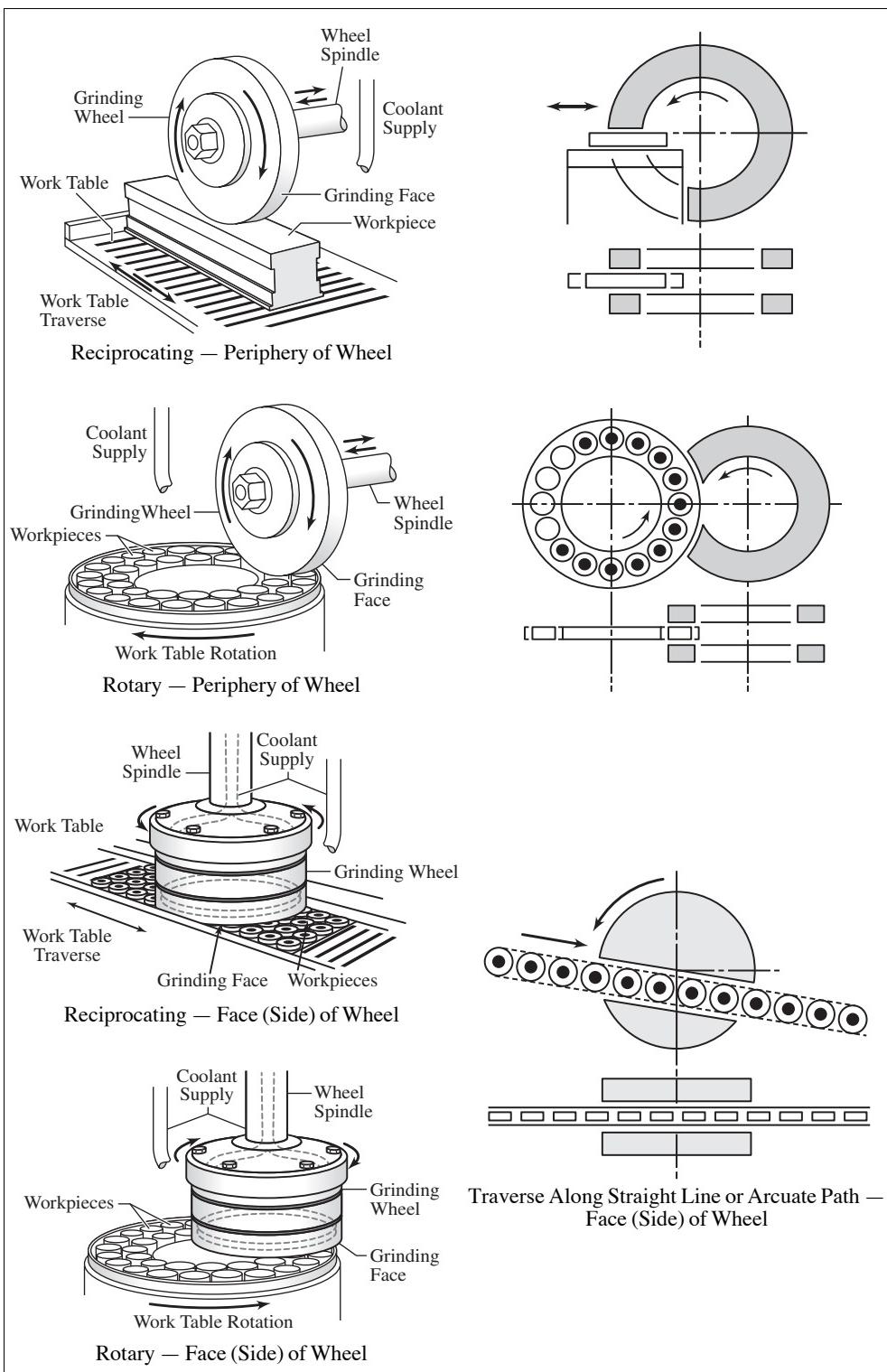
Table 2. Maximum Peripheral Speeds for Grinding Wheels
Based on ANSI B7.1-1988

| Classification No. | Types of Wheels ^a | Maximum Operating Speeds, sfpm, Depending on Strength of Bond | |
|--------------------|---|---|------------------------------|
| | | Inorganic Bonds | Organic Bonds |
| 1 | Straight wheels — Type 1, except classifications 6, 7, 9, 10, 11, and 12 below Type 4 ^b — Taper Side Wheels Types 5, 7, 20, 21, 22, 23, 24, 25, 26 Dish wheels — Type 12 Saucer wheels — Type 13 Cones and plugs — Types 16, 17, 18, 19 | 5,500 to 6,500 | 6,500 to 9,500 |
| 2 | Cylinder wheels — Type 2 Segments | 5,000 to 6,000 | 5,000 to 7,000 |
| 3 | Cup shape tool grinding wheels — Types 6 and 11 (for fixed base machines) | 4,500 to 6,000 | 6,000 to 8,500 |
| 4 | Cup shape snagging wheels — Types 6 and 11 (for portable machines) | 4,500 to 6,500 | 6,000 to 9,500 |
| 5 | Abrasive disks | 5,500 to 6,500 | 5,500 to 8,500 |
| 6 | Reinforced wheels — except cutting-off wheels (depending on diameter and thickness) | ... | 9,500 to 16,000 |
| 7 | Type 1 wheels for bench and pedestal grinders, Types 1 and 5 also in certain sizes for surface grinders | 5,500 to 7,550 | 6,500 to 9,500 |
| 8 | Diamond and cubic boron nitride wheels Metal bond Steel centered cutting off | to 6,500 to 12,000 to 16,000 | to 9,500 ... to 16,000 |
| 9 | Cutting-off wheels — Larger than 16-inch diameter (incl. reinforced organic) | ... | 9,500 to 14,200 |
| 10 | Cutting-off wheels — 16-inch diameter and smaller (incl. reinforced organic) | ... | 9,500 to 16,000 |
| 11 | Thread and flute grinding wheels | 8,000 to 12,000 | 8,000 to 12,000 |
| 12 | Crankshaft and camshaft grinding wheels | 5,500 to 8,500 | 6,500 to 9,500 |

^a See Tables 7a and Tables 7b starting on page 212.

^b Non-standard shape. For snagging wheels, 16 inches and larger — Type 1, internal wheels — Types 1 and 5, and mounted wheels, see ANSI B7.1-1988. Under no conditions should a wheel be operated faster than the maximum operating speed established by the manufacturer.

Values in this table are for general information only.

Table 3. Principal System of Surface Grinding Diagrams

Principals of Operations

Periphery of Wheel.— *Reciprocating*: Work is mounted on the horizontal machine table that is traversed in a reciprocating movement at a speed generally selected from a steplessly variable range. The transverse movement, called cross feed of the table or of the wheel slide, operates at the end of the reciprocating stroke and assures the gradual exposure of the entire work surface, which commonly exceeds the width of the wheel. The depth of the cut is controlled by the downfeed of the wheel, applied in increments at the reversal of the transverse movement.

Rotary : Work is mounted, usually on the full-diameter magnetic chuck of the circular machine table that rotates at a preset constant or automatically varying speed, the latter maintaining an approximately equal peripheral speed of the work surface area being ground. The wheelhead, installed on a cross slide, traverses over the table along a radial path, moving in alternating directions, toward and away from the center of the table. Infeed is by vertical movement of the saddle along the guideways of the vertical column, at the end of the radial wheelhead stroke. The saddle contains the guideways along which the wheelhead slide reciprocates.

Face (Side) of Wheel.— *Reciprocating* : Operation is similar to the reciprocating table-type peripheral surface grinder, but grinding is with the face, usually with the rim of a cup-shaped wheel, or a segmental wheel for large machines. Capable of covering a much wider area of the work surface than the peripheral grinder, thus frequently no need for cross feed. Provides efficient stock removal, but is less adaptable than the reciprocating table-type peripheral grinder.

Rotary : The grinding wheel, usually of segmental type, is set in a position to cover either an annular area near the periphery of the table or, more commonly, to reach beyond the table center. A large circular magnetic chuck generally covers the entire table surface and facilitates the mounting of workpieces, even of fixtures, when needed. The uninterrupted passage of the work in contact with the large wheel face permits a very high rate of stock removal and the machine, with single or double wheelhead, can be adapted also to automatic operation with continuous part feed by mechanized work handling.

Traverse Along Straight or Arcuate Path: Operates with practically the entire face of the wheel, which is designated as an abrasive disc (hence “disc grinding”) because of its narrow width in relation to the large diameter. Built either for one or, more frequently, for two discs operating with opposed faces for the simultaneous grinding of both sides of the workpiece. The parts pass between the operating faces of the wheel (a) pushed-in and retracted by the drawerlike movement of a feed slide; (b) in an arcuate movement carried in the nests of a rotating feed wheel; (c) nearly diagonally advancing along a rail. Very well adapted to fully mechanized work handling.

Table 3a. Grinding Wheel Recommendations for Surface Grinding Using Type 2 Cylinder Wheels, Type 6 Cup Wheels, and Wheel Segments

| Material | Type 2 Cylinder Wheels | Type 6 Cup Wheels | Wheel Segments |
|---|------------------------------|------------------------------|------------------------------|
| High tensile cast iron and nonferrous metals | 37C24-HKV | 37C24-HVK | 37C24-HVK |
| Soft steel, malleable cast iron, steel castings, Boiler plate | 23A24-I8VBE or 23A30-G12VBEP | 23A24-I8VBE | 23A24-I8VSM or 23A30-H12VSM |
| Hardened steel—broad contact | 32A46-G8VBE or 32A36-E12VBEP | 32A46-G8VBE or 32A60-E12VBEP | 32A36-G8VBE or 32A46-E12VBEP |
| Hardened steel—narrow contact or interrupt cut | 32A46-H8VBE | 32A60-H8VBE | 32A46-G8VBE or 32A60-G12VBEP |
| General-purpose use | 23A30-H8VBE or 23A30-E12VBEP | ... | 23A30-H8VSM or 23A30-G12VSM |

The wheel markings in the tables are those used by the Norton Co., complementing the basic standard markings with Norton symbols. The complementary symbols used in these tables, that is, those preceding the letter designating A (aluminum oxide) or C (silicon carbide), indicate the special type of basic abrasive that has the friability best suited for particular work materials. Those preceding A (aluminum oxide) are

57—a versatile abrasive suitable for grinding steel in either a hard or soft state.

38—the most friable abrasive.

32—the abrasive suited for tool steel grinding.

23—an abrasive with intermediate grinding action, and

19—the abrasive produced for less heat-sensitive steels.

Those preceding C (silicon carbide) are

37—a general application abrasive, and

39—an abrasive for grinding hard cemented carbide.

Table 4. Basic Process Data for Peripheral Surface Grinding on Reciprocating Table Surface Grinders

| Work Material | Hardness | Material Condition | Wheel Speed, fpm | Table Speed, fpm | Downfeed, in. per pass | | Crossfeed per pass, fraction of wheel width |
|-------------------------------|----------------|---|------------------|------------------|------------------------|-------------|---|
| | | | | | Rough | Finish | |
| Plain carbon steel | 52 Rc max. | Annealed, Cold drawn | 5500 to 6500 | 50 to 100 | 0.003 | 0.0005 max. | $\frac{1}{4}$ |
| | 52 to 65 Rc | Carburized and / or quenched and tempered | 5500 to 6500 | 50 to 100 | 0.003 | 0.0005 max. | $\frac{1}{10}$ |
| Alloy steels | 52 Rc max. | Annealed or quenched and tempered | 5500 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{4}$ |
| | 52 to 65 Rc | Carburized and/or quenched and tempered | 5500 to 6500 | 50 to 100 | 0.003 | 0.0005 max. | $\frac{1}{10}$ |
| Tool steels | 150 to 275 Bhn | Annealed | 5500 to 6500 | 50 to 100 | 0.002 | 0.0005 max. | $\frac{1}{5}$ |
| | 56 to 65 Rc | Quenched and tempered | 5500 to 6500 | 50 to 100 | 0.002 | 0.0005 max. | $\frac{1}{10}$ |
| Nitriding steels | 200 to 350 Bhn | Normalized, annealed | 5500 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{4}$ |
| | 60 to 65 Rc | Nitrided | 5500 to 6500 | 50 to 100 | 0.003 | 0.0005 max. | $\frac{1}{10}$ |
| Cast steels | 52 Rc max. | Normalized, annealed | 5500 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{4}$ |
| | Over 52 Rc | Carburized and/or quenched and tempered | 5500 to 6500 | 50 to 100 | 0.003 | 0.0005 max. | $\frac{1}{10}$ |
| Gray irons | 52 Rc max. | As cast, annealed, and/or quenched and tempered | 5000 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{3}$ |
| Ductile irons | 52 Rc max. | As cast, annealed or quenched and tempered | 5500 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{5}$ |
| Stainless steels, martensitic | 135 to 235 Bhn | Annealed or cold drawn | 5500 to 6500 | 50 to 100 | 0.002 | 0.0005 max. | $\frac{1}{4}$ |
| | Over 275 Bhn | Quenched and tempered | 5500 to 6500 | 50 to 100 | 0.001 | 0.0005 max. | $\frac{1}{8}$ |
| Aluminum alloys | 30 to 150 Bhn | As cast, cold drawn or treated | 5500 to 6500 | 50 to 100 | 0.003 | 0.001 max. | $\frac{1}{3}$ |

Table 5. Common Faults and Possible Causes in Surface Grinding

| Causes | Faults | Work Dimension | | | Metallurgical Defects | | Surface Quality | | | Wheel Condition | | | Work Retainment | | |
|------------------------|-----------------------------------|----------------|-------------------|-------------------|-----------------------|---------------------|-----------------|---------------|----------------------|-----------------|---------------|---------------|------------------|-------------------|-----------------------|
| | | Work not flat | Work not parallel | Poor size holding | Burnishing of work | Burning or checking | Feed lines | Chatter marks | Scratches on surface | Poor finish | Wheel loading | Wheel glazing | Rapid wheel wear | Not firmly seated | Work sliding on chuck |
| Work Condition | Heat treat stresses | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Work too thin | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Work warped | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ✓ | ... |
| | Abrupt section changes | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Grinding Wheel | Grit too fine | ... | ... | ... | ✓ | ✓ | ... | ... | ... | ... | ✓ | ✓ | ... | ... | ... |
| | Grit too coarse | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Grade too hard | ✓ | ... | ... | ✓ | ✓ | ... | ✓ | ... | ... | ✓ | ✓ | ... | ... | ... |
| | Grade too soft | ... | ... | ✓ | ... | ... | ... | ✓ | ✓ | ... | ... | ... | ✓ | ... | ... |
| | Wheel not balanced | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ... | ... | ... |
| | Dense structure | ... | ... | ... | ... | ... | ... | ... | ... | ... | ✓ | ✓ | ... | ... | ... |
| Tooling And Coolant | Improper coolant | ... | ... | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... |
| | Insufficient coolant | ✓ | ✓ | ... | ✓ | ✓ | ... | ... | ... | ... | ... | ✓ | ... | ... | ... |
| | Dirty coolant | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ✓ | ... | ... | ... | ... |
| | Diamond loose or chipped | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ✓ | ✓ | ✓ | ... | ... | ... |
| | Diamond dull | ... | ... | ✓ | ... | ... | ... | ... | ... | ✓ | ✓ | ✓ | ... | ... | ... |
| | No or poor magnetic force | ... | ... | ✓ | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ✓ | ... |
| | Chuck surface worn or burred | ✓ | ✓ | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ✓ | ✓ |
| Machine And Setup | Chuck not aligned | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Vibrations in machine | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ... | ... | ... |
| | Plane of movement out of parallel | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Operational Conditions | Too low work speed | ... | ... | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... |
| | Too light feed | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... |
| | Too heavy cut | ✓ | ... | ... | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Chuck retained swarf | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Chuck loading improper | ✓ | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Insufficient blocking of parts | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ... | ... |
| | Wheel runs off the work | ... | ✓ | ✓ | ... | ... | ✓ | ... | ... | ... | ... | ... | ✓ | ... | ... |
| | Wheel dressing too fine | ✓ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | Wheel edge not chamfered | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ... | ... | ... |
| | Loose dirt under guard | ... | ... | ... | ... | ... | ... | ... | ✓ | ... | ... | ... | ... | ... | ... |

American National Standard Grinding Wheel Markings.—ANSI Standard B74.13-1990“Markings for Identifying Grinding Wheels and Other Bonded Abrasives,” applies to grinding wheels and other bonded abrasives, segments, bricks, sticks, hones, rubs, and other shapes that are for removing material, or producing a desired surface or dimension. It does not apply to specialties such as sharpening stones and provides only a standard system of markings. Wheels having the same standard markings but made by different wheel manufacturers may not—and probably will not—produce exactly the same grinding action. This desirable result cannot be obtained because of the impossibility of closely correlating any measurable physical properties of bonded abrasive products in terms of their grinding action.

Sequence of Markings.—The accompanying illustration taken from ANSI B74.13-1990 shows the makeup of a typical wheel or bonded abrasive marking.

| Prefix | 1 Abrasive Type | 2 Grain Size | 3 Grade | 4 Structure | 5 Bond Type | 6 Manufacturer's Record |
|--------|-----------------------|--------------------|------------|----------------|-------------------|-------------------------------|
|--------|-----------------------|--------------------|------------|----------------|-------------------|-------------------------------|

51 — A — 36 — L — 5 — V — 23

The meaning of each letter and number in this or other markings is indicated by the following complete list.

1) *Abrasive Letters*: The letter (A) is used for aluminum oxide, (C) for silicon carbide, and (Z) for aluminum zirconium. The manufacturer may designate some particular type in any one of these broad classes, by using his own symbol as a prefix (example, 51).

2) *Grain Size*: The grain sizes commonly used and varying from coarse to very fine are indicated by the following numbers: 8, 10, 12, 14, 16, 20, 24, 30, 36, 46, 54, 60, 70, 80, 90, 100, 120, 150, 180, and 220. The following additional sizes are used occasionally: 240, 280, 320, 400, 500, and 600. The wheel manufacturer may add to the regular grain number an additional symbol to indicate a special grain combination.

3) *Grade*: Grades are indicated by letters of the alphabet from A to Z in all bonds or processes. Wheel grades from A to Z range from soft to hard.

4) *Structure*: The use of a structure symbol is optional. The structure is indicated by numbers. 1 to 16 (or higher, if necessary) with progressively higher numbers indicating a progressively wider grain spacing (more open structure).

5) *Bond or Process*: Bonds are indicated by the following letters: V, vitrified; S, silicate; E, shellac or elastic; R, rubber; RF, rubber reinforced; B, resinoid (synthetic resins); BF, resinoid reinforced; O, oxychloride.

6) *Manufacturer's Record*: The sixth position may be used for manufacturer's private factory records; this is optional.

Composition of Diamond and Cubic Boron Nitride Wheels.—According to American National Standard ANSI B74.13-1990, a series of symbols is used to designate the composition of these wheels. An example is shown below.

| Prefix | Abrasive | Grain Size | Grade | Concentration | Bond Type | Bond Modifi- cation | Depth of Abrasive | Manufacturer's Identification Symbol |
|--------|----------|---------------|-------|---------------|--------------|---------------------------|----------------------|--|
| M | D | 120 | R | 100 | B | 56 | 1/8 | * |

Fig. 4. Designation Symbols for Composition of Diamond and Cubic Boron Nitride Wheels

The meaning of each symbol is indicated by the following list:

1) *Prefix*: The prefix is a manufacturer's symbol indicating the exact kind of abrasive. Its use is optional.

2) *Abrasive Type*: The letter (B) is used for cubic boron nitride and (D) for diamond.

3) *Grain Size*: The grain sizes commonly used and varying from coarse to very fine are indicated by the following numbers: 8, 10, 12, 14, 16, 20, 24, 30, 36, 46, 54, 60, 70, 80, 90, 100, 120, 150, 180, and 220. The following additional sizes are used occasionally: 240, 280, 320, 400, 500, and 600. The wheel manufacturer may add to the regular grain number an additional symbol to indicate a special grain combination.

4) *Grade*: Grades are indicated by letters of the alphabet from A to Z in all bonds or processes. Wheel grades from A to Z range from soft to hard.

5) *Concentration*: The concentration symbol is a manufacturer's designation. It may be a number or a symbol.

6) *Bond*: Bonds are indicated by the following letters: B, resinoid; V, vitrified; M, metal.

7) *Bond Modification*: Within each bond type a manufacturer may have modifications to tailor the bond to a specific application. These modifications may be identified by either letters or numbers.

8) *Abrasive Depth*: Abrasive section depth, in inches or millimeters (inches illustrated), is indicated by a number or letter which is the amount of total dimensional wear a user may expect from the abrasive portion of the product. Most diamond and CBN wheels are made with a depth of coating on the order of $\frac{1}{16}$ in., $\frac{1}{8}$ in., or more as specified. In some cases the diamond is applied in thinner layers, as thin as one thickness of diamond grains. The L is included in the marking system to identify a layered type product.

9) *Manufacturer's Identification Symbol*: The use of this symbol is optional.

Table 6. Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|--|--|
| Alnico | |
| Offhand | 23AC36–N5B5 |
| Cylindrical | 3SGP60–JVS or 53A60–J8V127 |
| Surfacing (Straight Wheel) | 3SGP60–IVS or 86A60–H10VH |
| Surfacing (Segments) | 86A46–D12VBEP |
| Centerless | 57A60–K8VCN or 53A60–K8VCN |
| Internal | 32A60–J6VBE |
| Aluminium | |
| Cylindrical | 86A54–J8V127, 53A54–J8VBE or 37C54–KVK |
| Centerless (Hard) | 32A46–L7VBE or 86A46–LV127 |
| Centerless (Soft) | 37C46–LVK or 23AC46–LB24 |
| Bars | 32AC54–QB |
| Surfacing (Straight Wheel) | 37C36–J8V |
| Surfacing (Segments) | 5SG46–E12VSP, 86A46–D12VBEP, or Pacesetter 30E |
| Internal | 37C36–K5V |
| Mounted Wheels | WNA25 |
| Floor Stands | AC202–Q5B38S |
| Portable Grinders | AC24–P |
| Aluminium Alloys | |
| Cylindrical | 37C54–JVK #12 Treat |
| Bolts (Screws and Studs) | |
| Cylindrical | 64A60–M8V127 |
| Centerless (Shoulder Grinder) | 57A60–M8VCN |
| Brass and Soft Bronze | |
| Centerless | 37C36–LVK |
| Cylindrical | 37C36–KVK |
| Internal | 37C36–K8VK or 37C46–J5V |
| Surfacing ^a (Straight Wheels) | 37C36–J8V |
| Surfacing ^a (Cylinder, cups) | 37C24–H8V |
| Surfacing ^a (Segments) | Pacesetter 30G |
| Snagging (Floor stands) up to 12,500 SFPM | AC202–Q5B38S |
| Broaches | |
| Sharpening | 5SG60–LVS or 5SG60–JVSP |
| Backing-off | 5SG46–KVS |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|--|--|
| Bronze (Hard) | |
| Centerless | 57A46–L8VCN, 64A46–MCVE, or AC46–PB24X813 |
| Cylinder, cups | 53A30–G12VBEP |
| Segments ^a | Pacesetter 30G |
| Cylindrical | 64A46–K8V127 or 57A46–L8VBE |
| Internal ^a | 57A60–LVFL |
| Portable | AC24–P |
| Snagging (Floor stands) up to 12,500 SFPM | AC202–Q5B38S |
| Cutting off (Dry) | 4NZ24–VB65B or 4NZ24–ZBNC |
| Surfacing (Straight Wheels) | 53A36–K8VBE |
| Bushings (Hardened Steel) | |
| Hardened Steel | 57A60–L8VCN or 86A60–L8VCN |
| Centerless | 3SGP60–LVS, 86A60–KV8127, or 23A60–L5VBE |
| Cylindrical | 53A60–K6VBE |
| Internal | 37C46–OVK |
| Bronze, Centerless | |
| Cast Iron | 3A46–J8VBE, 86A46–I8V127, or 37C46–KVK |
| Cylindrical | 37C46–J5V or 32A60–K6VBE |
| Internal | 32A60–H8VBE or 39C60–I8VK |
| Toolroom | |
| Surface (Dry) | 38A46–H8VBE |
| Cast Iron | |
| Cam Grinding | 3SGP60–L10VH or 57A54 –L8V127 |
| Roughing | 57A80–L8V127 |
| Finishing | 57A60–M8V128 |
| Dual Cycle | |
| Regrinding | 57A54–L8V127 |
| Crankshaft Grinding | |
| Pins | 86A60–NVS |
| Bearings | 86A60–MVS |
| Center Thrust Bearing | 86A60–MVS |
| Centerless | 3SG46–T23B80, 37C46–LVK, 64A60–LVCE, 57A54–K8VCN, or 32AC54–QB |
| Cylindrical | 37C46–JVK, 86A46–I8V127, or 32A46–J8VBE |
| Internal ^a | 37C46–J5V or 53A60–JVFL |
| Offhand (Rough Blending), Mounted wheels | A36–SB or 3NZG36–WB25 |
| Surfacing | |
| Cylinders, cups (Ductile gray) | 53A30–G12VBEP |
| Cylinders, cups (Chilled) | 37C24–H8V |
| Cylinders, cups (Ni hard) | 53A30–G12VBEP |
| Segments ^a , Ductile, gray, Ni hard | Pacesetter 30G |
| Snagging | |
| Floor stands, up to 12,500 SFPM | |
| Light Pressure | 4ZF1634–Q5B38S |
| Heavy Pressure | 4ZF1434–R5B38S |
| Swing Frame, up to 12,500 SFPM | |
| Light Pressure | 4ZF1634–R5B38S |
| Heavy Pressure | 4ZF1234–R5B38S |
| Portable Grinder | |
| Type 01, up to 9500 SFPM | 4NZ1634–R5BSLX348 |
| Type 06 & 11 | 4NZ1634–R5BX348 |
| Chrome Plating | |
| Internal (Small Parts) | 37C80–KVK, 5SGG80–KVS, or 32A100–JVFL |
| Internal (Large Parts) | 3SG80–KVS, 32A80–112VBEP, or 53A80–K6VBE |
| Surfacing (Straight Wheels) | 32A80–I8VBE, 5SG80–IVS, or 3SG80–GVSP |
| Cylindrical (Commercial Finish) | 3SGP80–JVS or 53A80–J8V127 |
| Cylindrical (Good Commercial Finish) | AI50–K5E |
| Cylindrical (High Finish Reflective) | 37C500–I984 |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|---|
| Copper | |
| Cylindrical (also see rolls) | 37C60-KVK |
| Cylindrical (Cups and Cylinders) | 37C16-JVK |
| Copper Alloys | |
| Cylindrical | 37C46-KVK |
| Surfacing (Horizontal Spindle) | 39C36-I8V #12 Treat |
| Surfacing (Vertical Spindle) | |
| Roughing | 57AC46-JB24 |
| Finishing | 57AC60-JB24 |
| Knives, Carbon Steel and Stainless Steel | |
| Butcher, Hemming and Klotz machines | 53A120-OP1 |
| Kitchen, Hemming machines | 53A801-UP1 |
| Hollow Grinding | A60-F2RR |
| Cylinders (Air Craft) Internal^a | |
| Molybdenum Steel | |
| Roughing | 53A80-JVFL or 5TG120-JVFL |
| Finishing | 32A100-JVFL or 53A100-JVFL |
| Regrinding | 5TG120-JVFL |
| Nitrided | |
| Before nitriding | 37C80-I5V |
| After nitriding | 32A80-JVFL |
| Regrinding | 37C80-J5V |
| Dies (Blanking and Drawing) internal^a | |
| Carbon Steel | 5TG120-KVFL or 53A80-KVFL |
| High Carbon, high chrome | 3SG80-KVS or 53A80-K6VBE |
| Die Forging | |
| Offhand – Portable Grinding Mounted points and wheels | |
| Coarse | 5SG60-PVS or 38A80-PVME |
| Medium | 5SG90-QVS or 38A90-QVME |
| Fine | 5SG120-SVS or 38A120-QVM |
| Straight Wheels, Roughing | |
| 5000 – 6500 SFPM | 23A46-QVBE |
| 7000 – 9500 SFPM | A36-Q2BH |
| Dies (Steel) Drawing | |
| Surfacing – (Hardened) | |
| Straight Wheels (Dry) | 5SG60-GVSP, 5SG60-IVS, 32A60-F12VBEP, 32AA60-HVTRP, or 32A46-H8VBE |
| Straight Wheels (Fast, traverse, wet) | 5SG60-IVS, 32A60-I8VBE, or 32AA60-IVTR |
| Cup Wheels (wet) | 38A46-G8VBE |
| Segments ^a | 5SG46-DVSP |
| Surfacing – (Annealed) | |
| Straight Wheels (Dry) | 5SG60-JVS, 5SG60-HVSP, or 32AA60-IVTRP |
| Cup Wheels (Wet) | 32A24-H8VBE |
| Segments ^a | 86A30-F12VBEP or 5SG30-FVSP |
| Drills (Manufacturing) | |
| Cylindrical | 57A60-L8V127 |
| Centerless (Soft) | 57A60-M8VCN |
| Centerless (Hard) | 53A60-L8VCN or 57A60-L8VCN |
| Fluting | 57A1001-UB467 |
| Pointing | 57A1003-T9BX340 |
| Grinding Relief | 57A100-R4R30 |
| Drills (Resharpening) | |
| $\frac{1}{4}$ " and smaller | |
| Machine | 5SG100-IVS |
| Offhand | 57A80-L5VBE |
| $\frac{1}{4}$ " to 1" | |
| Machine | 5SG54-LVS |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|---|
| Drills (Resharpening) (Continued) | |
| Offhand | 5SG60-LVS |
| 1" and larger – Machine | 5SG46-HVSP |
| Winslowmatic Machine | |
| Web Thinning | 23A60-L7B5 |
| Pointing | 23A70-M7B5 or 5SGP80-KVSB |
| Hi – Production | |
| 5 hp machine | 57A1003-R9BX340 |
| 30 hp machine | 57A1003-T9BX340 |
| Ductile Iron | |
| General reinforced cut-off | U57A244-VB65B or U57A244-TBNC |
| Surfacing (segments) | See Cast Iron |
| Fasteners (Steel) | |
| Centerless | 57A80-M8VCN |
| Forgings | |
| Centerless | 57A60-M8VCN |
| Cylindrical | 64A54-L8V127 or 57A54-M8VBE |
| Gages | |
| Plug | |
| Cylindrical | 64A80-J8V127 or 57A80-K8VBE |
| Cylindrical, High Finish | 37C500-J9E |
| Thread | |
| Threads, 12 pitch and coarser | 32A100-K8VBE or 32A100-KBVH |
| Threads, 13 – 20 pitch | 32A120-K8VBE or 32A120-L8VH |
| Threads, 24 pitch and finer | 32A180-N9VG or 32A180-N10VH |
| Ring | |
| Internal (Roughing) | 5TG120-KVFL or 63A80-LVFL |
| Internal (Finishing) | 32A120-JVFL |
| Internal (Fine Finishing) | 37C320-J9E |
| Gears | |
| Case hardened, precut | |
| 18 – 20 DP | A120-K8BL or 32A120-K9VG |
| 5 – 18 DP | A80-I8BL or 32A60-J8VG |
| 2 – 5 DP | 32A60-J8VG |
| Casehardened from a solid, 18 DP or finer | A120-K8BL |
| Cast Iron, cleaning between teeth (offhand) | 37C24-T6R30 |
| Hardened Steel | |
| Internal ^a | 3SG60-KVS or 53A60-K6VBE |
| Surfacing (Cups and Cylinders) | 32A36-I8VBE |
| Surfacing (Segments) ^a | 86A36-E12VBEP |
| Surfacing (Straight Wheels) | 5SG60-JVS, 3SGP60-JVS, 5SG60-H12VSP, 3SG60-H12VSP, or 32A46-J8VBE |
| Hastalloy | |
| Surfacing | |
| Straight Wheel | 86A46-G10VH or 32A60-E25VCP |
| Straight Wheel, Creep Feed | 38A80-E19VCF2 or 38A80-F16VCF2 |
| Segments ^a | 5SG46-EVSP |
| Internal ^a | 5TG120-KVFL or 32A80-KVFL |
| Cylindrical | 5SGP80-JVS or 86A80-J8V127 |
| Centerless | 53A60-J8VCN or 57A54-K8VCN |
| Inconel or Inconel X (with heavy duty soluble or straight oil) | |
| Surfacing | |
| Straight Wheel | 3SGP60-H10VH, 32A60-F19VCP, 32AA60-IVTR, or 86A60-H10VH |
| Straight Wheel (Creep Feed) | 38A60-E25VCF2 or 38A602-F25VCF2 |
| Segments ^a | 5SG46-EVSP |
| Form Grinding | 3SGP60-J8VH or 53A60-J8VJN |
| Internal ^a | 5TG120-KVFL or 32A80-JVFL |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|--------------------------------|
| Inconel or Inconel X (with heavy duty soluble or straight oil) (Continued) | |
| Cylindrical | 3SGP60-I10VH or 86A80-J8V127 |
| Centerless | 5SG60-LVS or 57A60-K8VCN |
| Offhand (blending mounted wheels) | 5SG90-QVS or 5SG90-RVH |
| Thread | 38A180-N10VH or 38A180-N9VG |
| Cutting off (Dry) | 4NZ30-TB65W |
| Cutting off (Wet) | A461-P4R55 |
| Jet Blades | |
| Form Grinding | 38A602-F16VCF2 |
| Aerospace Alloys, Cutting Off Investment Casting Gates & Risers | |
| Chop Stroke | 90A244-VB97B |
| Locked Head – Push Thru | 90A244-VB97N |
| General Industrial | 4NZ30-TB65N |
| Lapping (General Purpose) | |
| Aluminium | 39C280-JVX142C |
| Brass | 37C180-J9V |
| Cast Iron | 37C180-J9V |
| Copper | 39C320-JVX142C |
| Stainless | 39C280-JVX142C |
| Steel | 39C220-I9V |
| Lawn Mowers | |
| Resharpening | 53A60-M8VBE |
| Lucite | |
| Centerless | 37C60-MVK |
| Magnesium Alloys | |
| Cylindrical | 37C60-KVK |
| Malleable Castings | |
| Portable Cut-off | U57A244-TB25N |
| General Reinforced Cut-off | U57A244-TB25N or U57A244 -TBNC |
| Floor stands and Swing Frames Up to 12,500 SFPM | |
| Light Pressure | 4ZF1434-Q5B38S |
| Heavy Pressure | 4ZF1434-R5838S |
| Portable Grinders Type 01, up to 9500 SFPM | 4NZ1634-R5BSLX348 |
| Portable Grinders Types 06 & 11 | 4NZ1634-R5SBX348 |
| Minerals – Lapidary (Offhand) | |
| Moh's Hardness 7 or less | |
| Roughing | 37C100-NVK |
| Finishing | 37C220-LVK |
| Moh's Hardness over 7 | |
| Roughing | 37C100-MVK |
| Finishing | 37C220-K8V |
| Cutting off (Wet) | See Superabrasives Section |
| Molybdenum^a | |
| Cylindrical | 57A60-K8V127 |
| Surfacing | 5SG60-IVS |
| Surfacing (Segments) | 5SG46-DVSP |
| Monel Metal | |
| Portable Cut-off | U57A244-TB25N |
| General Reinforced Cut-Off | U57A244-VB65B |
| Internal | 37C60-K6V |
| Cylindrical | 37C60-JVK |
| Nickel Based Superalloys | |
| Surfacing | 32A60-E25VCP |
| Cutting-off (Dry) Chop Stroke | 90A244-VB97B |
| Cutting-off (Dry) Locked Hd.Push Thru | 90A244-VB97N |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|-------------------------------------|
| Nickel Plate | |
| Surfacing Straight Wheel | 37C60–H8V |
| Surfacing Creep feed | 32A60–D28VCF2 |
| Nickel Rods and Bars | |
| General Reinforced Cut-off | 90A244–VB97B |
| Ni Hard | |
| Centerless | 53A80–K8VCN |
| Cylindrical | 3SGP80–JVS or 86A80–J8V127 |
| Internal | 53A80–K6VBE |
| Surfacing Wheels | 32A46–I8VBE |
| Surfacing Segments | Pacesetter 30G |
| Cuffing-off (General Reinforced) | U57A244–TBNC or 90A304–RB97B |
| Nitralloy (Cylindrical) | |
| Before Nitriding | 86A60–K8V127 |
| After Nitriding Commercial Finish | 35GP80–JVS or 86A80–J8V127 |
| After Nitriding High Finish | 37C100–IVK |
| After Nitriding Reflective Finish | 37C500–19E |
| Pipe | |
| Cast Iron | |
| Cleaning Inside | 4ZF1434–R5B38SL |
| General Reinforced Cut-off | 3NZF244–ZB65N |
| Steel, Finish Unimportant | |
| Cutting-off (General Reinforced) | 90A244–VB97N |
| Pipe Balls | |
| Centerless | 57A30–T5VBE |
| Regrind | 57A24–Q5VBE |
| Pistons | |
| Aluminum | |
| Cylindrical | 86A46–H8V127 or 53A46–I8V127 |
| Centerless | 37C46–KVK |
| Regrinding | 86A46–H8V127 |
| Cast Iron | |
| Cylindrical | 39C46–J8VK or 37C36–KVK |
| Centerless | 37C46–KVK |
| Regrinding | 23A46–I8VBE or 53A46–I8V127 |
| Piston Pins | |
| Centerless Machine Roughing | 5SG60–JVS, 32A54–QB, or 57A60–M8VCN |
| Centerless Machine Semi-finishing | 57A70–RB24X813 or 57A80–M8VCN |
| Piston Rings | |
| Cast Iron | |
| Surfacing Rough (Cylinders) | 32A30–H8VBE |
| Surfacing (Straight Wheels) | 32A80–K8VBE or 5SGG80–KVS |
| Internal (Snagging) | 5SGG46–KVS |
| Plasma Spray – Carbides, Chrome | |
| Centerless | |
| Roughing and Finishing | 39C80–H8VK |
| Finishing | 37C80–PB24 |
| Plastics | |
| Cylindrical (Thermoplastics) | |
| Wet | 37C46–JVK or 32A46–I12VBEP |
| Dry | 37C36–I5B |
| Thermosetting | |
| Surfacing (Straight Wheel), Thermoplastic | 37C30–I5B |
| Nylon | |
| Centerless | 37C46–KVK or 37C46–LVK |
| Surfacing | 23A36–L8VBE |
| Plexiglass | |
| Cut-off (Wet) | 37C60–M4R55 |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|---|
| Plastics (Continued) | |
| Surfacing Polystyrene, Centerless | 38A46–H12VBEP 37C46–KVK |
| Propeller Hubs (Cone Seals) Internal | |
| Rough and Finish Fine Finish | 38A60–K6VBE A120–M2R30 |
| Pulleys (Cast Iron) | |
| Cylindrical | 37C36–JVK |
| Rails | |
| Surfacing, Welds up to 9500 SFPM Cup Wheels Straight Wheels Removing Corrugations | 4NZ1634–R5BX348 4NZ1634–R5BSX348 4NZ1634–R5BSX348 |
| Reamers | |
| Backing-off Cylindrical | 32A46–K5VBE or 5SG46–K6VH 57A60–L8VBE |
| Rene | |
| Surfacing (Form Grinding) Straight Wheel (Creep Feed) Cutting-off | 5SG60–JVS, 3SG60–J10VH, or 53A60–J8VJN 38A80–F19VCF2 90A244–RB97B |
| Rods (Centerless) | |
| Miscellaneous Steel 300 Series Stainless Nitralloy (Before Nitriding) Silichrome Steel Brass and Bronze Hard Rubber Carbon Plastic | 57A60–M8VCN or 32A54–QB 37C54–NVK, 86A60–L8V127, 53A60–L8VCN, or 32AC54–QB 57A60–L8VCN 57A60–M8VCN or 32AC54–SB 37C60–KVK 37C30–KVR 37C36–NVK 32A80–N7VBE |
| Roller Bearing Cups | |
| Centerless O.D. Internal | 57A60–M8VCN or 64A60–NVCE 5TG120–KVFL or 53A80–LVFL |
| Rollers for Bearings | |
| Rollers (Cylinders) Small Large Fine Finish Rollers (Needle) Up to 1/8" diameter Over 1/8 to 3/8" diameter | 57A100–RB24 57A80–NB24 A100–R2R30 57AC120–TB24 5780–QB17X344 |
| Rotors (Laminated) (Cylindrical) | |
| Roughing Finishing | 86A100–H8V127 or 57A100–I8VBE 37C500–G9E |
| Rubber (Soft) | |
| Cylindrical (Dry) | 23A20–K5B7 or 32A46–G12VBEP |
| Rubber (Hard) | |
| Cylindrical | 37C36–J5V |
| Scissors and Shears | |
| Cast Iron, Surfacing Sides of Blades Steel, Resharpening, Small Wheels Steel, Resharpening, Large Wheels | 37C100–S8V 32A120–M7VBE 57A901–MV5 |
| Shafts (Centerless) | |
| Pinion Spline | 57A60–L8VCN or 32A54–QB 57A60–M8VCN |
| Shear Blades (Power Metal Shears) | |
| Sharpening (Segments) | 23A30–H8VBE |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|---|
| Sharpening (Cylinders) | 23A30-G8VBE |
| Spline Shafts | |
| Centerless | 57A60-M8VCN or 64A60-NVCE |
| Cylindrical | 86A60-M8V 127 |
| Grinding Splines | 23A60-L5VBE |
| Steel Castings (Low Carbon) | |
| Cutting -off (Reinforced) | 90A244-TB97B or U57A244-XBNC |
| Floorstands up to 12,500 SFPM Light Pressure | 4ZF1434-Q5B38S |
| Floorstands up to 12,500 SFPM Heavy Pressure | 4ZF1434-R5B38S |
| Portable Grinders Type 01 | 4NZ1634-R5BSX348 |
| Portable Grinders Types 06 & 11 | 4NZ1634-R5BX348 |
| Steel Castings (Manganese) | |
| Floorstands up to 12,500 SFPM Light Pressure | 4ZF1634-Q5838S |
| Floorstands up to 12,500 SFPM Heavy Pressure | 4ZF1434-R5B38S |
| Portable Grinders Type 01 | 4NZ1634-R5BSX348 |
| Portable Grinders Types 06 & 11 | 4NZ1634-R5BX348 |
| Portable Internal — Rough Grinding Up to 9500 SFPM | Gemini |
| General Reinforced Cut-off | 90A244-TB97B or U57A244-XBNC |
| Steel forgings (Disc) | |
| Small-Light Work | 23A16-JB14 |
| Large – Heavy Work | 23A30-QB14 |
| Steel (Hard) (Rc 45 and harder)^b | |
| Centerless (Fine Finish) | A120-P4R30 |
| Centerless (Commercial Finish) | 53A60-K8VCN |
| Centerless (Feed Wheel) | A8O-RR51 |
| Cylindrical Parts smaller than 1" diameter | 3SGP80-JVS or 86A80-J8V127 |
| Cylindrical Parts 1" diameter & larger | 35GP60-JVS or 86A60-J8V127 |
| Internal | 5TG120-KVFL or 53A80-KVFL |
| Surfacing (Straight Wheels) | 5SG60-GVSP, 5SG46-IVS, 35GP60-JVS, 32A46-IVTR, 32A46-I8VBE, 86A60-F25VCP, or 32AA46-HVTRP |
| Surfacing (Segments) ^a broad area of contact | 5SG30-EVSP, 86A30-EL2VBEP, or Pacesetter 30G |
| Surfacing (Segments) ^a medium area of contact | 5SG30-FVSP, 86A30-F12VBEP or Pacesetter 30F |
| Surfacing (Segments) ^a narrow area of contact | 5SG30-GVSP, 86A30-G12VBEP or Pacesetter 30G |
| Surfacing (Cylinders) | 38A46-G8VBE |
| Steel (Soft) (Up to Rc 45) | |
| Portable Cut-off | U57A244-TB25N |
| General Reinforced Cut-off | 90A244-TB97B |
| Cylindrical 1" diameter and less | 57A60-L8V127 |
| Cylindrical Over 1" diameter | 57A54-K8V127 |
| Internal | 32A60-KVBE or 53A80-KVFL |
| Surfacing Straight Wheel | 53A36-K8VBE |
| Surfacing Segments | 86A30-F12VBEP, Pacesetter 30G, or 5SG30-GVSP |
| Steel (High Speed)^c | |
| Centerless Commercial Finish | 57A60-K8VCN |
| Centerless Fine Finish | A120-P4R30 |
| Feed Wheel | A8O-RR51 or A80-SR51 |
| Cylindrical 14" and Smaller | 3SGP60-LVS, 53A60-L5VBE, or 32A46-HI2VBEP |
| Cylindrical 16" and Larger | 3SGP60-MVS or 86A60-L8V127 |
| Internal | 5TG120-KVFL, 3SG60-KVS, 3SG60-FVSP, or 53A80-JVFL |
| Surfacing (Straight Wheels) | 5SG60-GVSP, 32AA60-HVTRP, 32A60-G25VCF2, or See Superabrasives |
| Surfacing (Cylinders) | 38A46-G8VBE |
| Surfacing (Segments) | 86A46-DI2VBEP or 55G46-EVSP |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|--|--|
| Steel (Stainless 17-4 PH)^d | |
| Surfacing Straight Wheel | 3SGP60-IVS, 32A60-I8VBE, 32A60-F25VCP, or 37C60-JVK |
| Internal | 23A60-K6VBE or 37C60-K6V |
| Cylindrical | 86A60-J8V127, 37C54-KVK, or 57A60-K5VBE |
| Centerless | 57A60-K8VCN |
| Steel (Stainless — 300 Series) | |
| Centerless | 53A54-K8VCN or 64A60-KVCE |
| Centerless (Feed Wheel) | A80-RR51 |
| Cylindrical | 37C54-JVK or 86A54-18V127 |
| Internal | 37C46-JVK |
| Off-hand (Rough Blending) Mounted Wheels | 4NZ36-WB25 or 3NZG36-WB25 |
| Surfacing (Straight Wheels) | 5SG60-IVSP, 3SGP60-IVSP, 32A46-J8VBE, or 32AA46-JVTR |
| Surfacing (Creepfeed) | 32A80-E19VCF2 or 39C80-F24VCC |
| Surfacing (Cups) | 38A46-I8VBE |
| Surfacing (Cylinders) | 32A46-G8VBE |
| Surfacing (Segments) | 86A46-D12VBEP, 5SG46-DVSP, or 57AC46-FB17 |
| Surfacing (Form Grinding) | 53A60-J8VJN |
| Steel (Stainless steel — 400 Series Hardened)^d | |
| Centerless Commercial Finish | 57A60-K8VCN or 64A60-LVCE |
| Centerless Fine Finish | A120-P4R30 |
| Centerless Feed Wheel | A80-RR51 or ASO-SR51 |
| Cylindrical Small Wheel | 53A60-K8VBE |
| Cylindrical Large Wheel | 86A60-J8V127 |
| Internal | 5TG120-KVFL or 53A80-KVFL |
| Off-hand (Rough Blending) Mounted Wheels | 4NZ36-UB25 or 3NZG36-UB25 |
| Surfacing (Straight Wheels) | 5SG60-IVS, 32A46-IVS, or 32AA46-IVTR |
| High Speed | 5SG60-IVS or 32A46-H8VBE |
| Surfacing (Creep feed) | 38A60-F19VCF2 or 86A60-F25VCP |
| Surfacing (Cylinders) | 32A36-G8VBE |
| Surfacing (Segments) | 5SG30-FVSP, 86A30-E12VBEP, or Pacesetter 305 |
| Surfacing (Form Grinding) | 3SG60-I10VH, 53A60-I8VJN, or 53A60-J8VJN |
| Stellite (also Rexalloy, Tantung) | |
| Cylindrical | 3SGP80-JVS, 38A80-J8V127, or 86A80-J8V127 |
| Cutter Grinding | 5SG46-JVS, 32A46-J8VBE, or 32AA46-JVTR |
| Internal | 3SG60-JVS or 53A60-J6VBE |
| Surfacing (Cups and Cylinders) | 32A46-G8VBE or 5SG46-IVS |
| Surfacing (Straight Wheels) | 5SG60-IVS, 5SG60-GVSP, 32A46-H8VBE, or 32AA46-IVTR |
| Tools Offhand | 57A46-NSVBE |
| Tools Machine | 5SG46-LVS, 32A46-L8VBE, or 32A46-LVTR |
| Tantalum | |
| Cylindrical | 86A60-J8V127 |
| Surfacing | 23A46-J8VBE |
| Tappets (Centerless) | |
| Steel Roughing | 57A60-M8VCN |
| Steel Finishing | 57A80-M8VCN |
| Cast Iron Roughing | 37C46-NVK |
| Cast Iron Finishing | 37C80-MVK |
| Taps (also see Toolroom Grinding Section) | |
| Fluting (Taps) | 57A1003-UB354 |
| Grinding Relief | 5SG60-KVS or 32A60-K8VBE |
| Squaring Ends | 32A801-Q8B5 or 5SG80-JVS |
| Shanks (Cylindrical) | 5SG80-LVS or 57A80-L8V127 |
| Titanium Precision Grinding | |
| Surfacing, Straight wheel, rust inhibitor coolant 2000 SFPM | 32A60-L8VBE or 5SGG60-LVS |
| 5500 SFPM | 5SG60-JVS, 39C60-J8VK, or 5SGG60-JVS |

Table 6. (Continued) Conventional Abrasives—Grinding Wheel Recommendations

| Characteristics | Recommendations |
|---|---|
| Titanium Precision Grinding (Continued) | |
| Vertical Spindle | 39C80—I8VK |
| Offhand (Blending) Mounted wheels | 5SG60—QVS or TG60—QVH |
| Cylindrical | 37C60—JVK |
| Centerless | 37C54—LVK or 37C54—PB24 |
| Creepfeed | 39C46—G24VX530 |
| Tools — Single Point Carbon and High Speed Steel | |
| Offhand Grinding Bench and Pedestal Grinders | |
| Coarse | 57A36—O5VBE or General Purpose Coarse |
| Fine | 57A60—M5VBE or General Purpose Fine |
| Combination (Roughing and finishing) | 57A46—N5VBE or General Purpose Medium |
| Wet Tool Grinders | |
| 12" to 24" diameter wheels | 57A36—O5VBE |
| Over 24" diameter wheels | 57A24—M5VBE |
| Machine Grinding | |
| Straight Wheels | |
| 15" diameter wheels | 23A46—L5VBE |
| 24" diameter wheels | 23A24—M5VBE |
| Cup or Cylinder Wheels | 38A46—K5VBE |
| Tungsten | |
| Cylindrical, Rolled Tungsten | 86A54—K8V127 |
| Cylindrical, Sintered Tungsten | 37C60—JVK |
| Centerless, Rolled Tungsten | 32A46—N5VBE |
| Centerless, Sintered Tungsten | 37C601—KVK |
| Internal | 5SG60—IJS |
| Surfacing 2000 SFPM | 23A46—J8VBE |
| Surfacing 5000 SFPM | 37C46—J8V |
| Udimet | |
| Surfacing (Form Grinding) | 3SG60—J8VH, 5SG60—JVS, or 53A60—J8VJN |
| Valves (Automotive) | |
| Refacing | 37C80—NVK or 57A80—J5VBE |
| Stems Centerless | 3TG120/3—P8VH, 3SGP70—OVH, or 57A60—M8VCN |
| Waspalloy (with Straight Oil) | |
| Surfacing (Form Grinding) | 53A60—J8VJN, 5SG60—JVS or 3SG60—K8VH |
| Surfacing (Straight wheels) | 5SG60—JVS, 3SGP60—JVS, 32A60—F19VCP, 32A46—IBVBE, or 32AA46—IVTR |
| Vertical Spindle | 32A36—E19VBEP or 32A46—E19VCP |
| Internal | 3SG60—JVS or 32A60—J6VBE |
| Cylindrical | 3SGP60—JVS, 86A60—J8VBE, or 53A60—J8VBE |
| Centerless | 53A60—J8VCN or 86A60—JV127 |
| Cuffing-off (general reinforced) | 90A244—TB97B |
| Welds (Carbon Alloy Steels) | |
| Portable Grinders Type 01 (to 9,500 SFPM) | 4NZ1634—Q5BSX348 |
| Portable Grinders Type 27 (to 16,000 SFPM) | NORZON |
| Stainless Steel Offhand (Rough Blending) Mounted Wheels | 4NZ30—WB25 or 3NZG30—WB25 |
| Portable Grinders Type 01 (9,500 SFPM) | 4NZ1634—Q5BSX348 |
| Portable Grinders Type 27 (to 16,000 SFPM) | NORZON |

^a Use of wax stick recommended^b CBN wheels are recommended for hard steel where tolerance, productivity and/or problems exist with conventional abrasives^c CBN wheels have successfully ground HSS under certain conditions^d CBN wheels are successfully grinding stainless under certain conditions

In addition to the abrasive specifications in this table, so-called super abrasives are available for special applications involving difficult to grind materials and where specific surface finish requirements must be met. Consult grinding wheel manufacturers for specific recommendations concerning super abrasives.

American National Standard Shapes and Sizes of Grinding Wheels.— ANSI Standard B74.2-1982 includes shapes and sizes of grinding wheels, gives a wide variety of grinding wheel shape and size combinations which are suitable for the majority of applications. Although grinding wheels can be manufactured to shapes and dimensions different from those listed, it is advisable, for reasons of cost and inventory control, to avoid using special shapes and sizes, unless technically warranted.

Standard shapes and size ranges as given in this Standard together with typical applications are shown in Table 7a for inch dimensions and in Table 7b for metric dimensions.

Table 7a. Standard Shapes and Inch Size Ranges of Grinding Wheels ANSI B74.2-1982

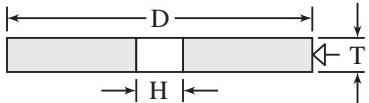
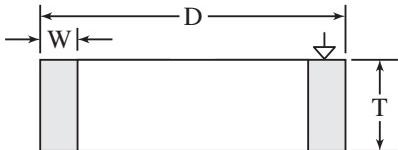
| Applications | Size Ranges of Principal Dimensions, Inches | | |
|---|--|------------|-----------------|
| | D = Dia. | T = Thick. | H = Hole |
|  | Type 1. Straight Wheel For peripheral grinding. | | |
| Cylindrical Grinding | | | |
| Between centers | 12 to 48 | ½ to 6 | 5 to 20 |
| Centerless grinding wheels | 14 to 30 | 1 to 20 | 5 or 12 |
| Centerless regulating wheels | 8 to 14 | 1 to 12 | 3 to 6 |
| Offhand Grinding, Grinding on the periphery | | | |
| General purpose | 6 to 36 | ½ to 4 | ½ to 3 |
| For wet tool grinding only | 30 or 36 | 3 or 4 | 20 |
| Snagging | | | |
| Floor stand machines | 12 to 24 | 1 to 3 | 1¼ to 2½ |
| Floor stand machines (Organic bond, wheel speed over 6500 sfpm) | 20 to 36 | 2 to 4 | 6 or 12 |
| Mechanical grinders (Organic bond, wheel speed up to 16,500 sfpm) | 24 | 2 to 3 | 12 |
| Portable machines | 3 to 8 | ¼ to 1 | ¾ to ⅝ |
| Portable machines (Reinforced organic bond, 17,000 sfpm) | 6 or 8 | ¾ or 1 | 1 |
| Swing frame machines | 12 to 24 | 2 to 3 | 3½ to 12 |
| Other | | | |
| Cutting Off, Organic bonds only | 1 to 48 | ⅛ to ¾ | ⅛ to 6 |
| Internal Grinding | ¼ to 4 | ¼ to 2 | ¾ to ⅜ |
| Saw Gumming, F-type face | 6 to 12 | ¼ to 1½ | ½ to 1¼ |
| Surface Grinding, Horizontal spindle machines | 6 to 24 | ½ to 6 | 1¼ to 12 |
| Tool Grinding, Broaches, cutters, mills, reamers, taps, etc. | 6 to 10 | ¼ to ½ | ⅝ to 5 |
|  | Type 2. Cylindrical Wheel Side grinding wheel — mounted on the diameter; may also be mounted in a chuck or on a plate. | | |
| | | | <i>W = Wall</i> |
| Surface Grinding Vertical spindle machines | 8 to 20 | 4 or 5 | 1 to 4 |

Table 7a. Standard Shapes and Inch Size Ranges of Grinding Wheels ANSI B74.2-1982

| Applications | Size Ranges of Principal Dimensions, Inches | | |
|--|--|------------|---------------|
| | D = Dia. | T = Thick. | H = Hole |
| | Type 5. Wheel , recessed one side For peripheral grinding. Allows wider faced wheels than the available mounting thickness, also grinding clearance for the nut and flange. | | |
| Cylindrical Grinding, Between centers | 12 to 36 | 1½ to 4 | 5 or 12 |
| Cylindrical Grinding, Centerless regulating wheel | 8 to 14 | 3 to 6 | 3 or 5 |
| Internal Grinding | ¾ to 4 | ¾ to 2 | ⅛ to ⅜ |
| Surface Grinding Horizontal spindle machines | 7 to 24 | ¾ to 6 | 1¼ to 12 |
| | Type 6. Straight-Cup Wheel Side grinding wheel, in whose dimensioning the wall thickness (W) takes precedence over the diameter of the recess. Hole is 5/8-11UNC-2B threaded for the snagging wheels and ½ or 1¼" for the tool grinding wheels. $W = \text{Wall}$ | | |
| Snagging, Portable machines, organic bond only. | 4 to 6 | 2 | ¾ to 1½ |
| Tool Grinding Broaches, cutters, mills, reamers, taps, etc. | 2 to 6 | 1 ¼ to 2 | 5/16 or ¾ |
| | Type 7. Wheel , recessed two sides Peripheral grinding. Recesses allow grinding clearance for both flanges and narrower mounting thickness than overall thickness. | | |
| Cylindrical Grinding, Between centers | 12 to 36 | 1½ to 4 | 5 or 12 |
| Cylindrical Grinding, Centerless regulating wheel | 8 to 14 | 4 to 20 | 3 to 6 |
| Surface Grinding, Horizontal spindle machines | 12 to 24 | 2 to 6 | 5 to 12 |
| | Type 11. Flaring-Cup Wheel Side grinding wheel with wall tapered outward from the back; wall generally thicker in the back. | | |
| Snagging, Portable machines, organic bonds only, threaded hole | 4 to 6 | 2 | 5/8-11 UNC-2B |
| Tool Grinding, Broaches, cutters, mills, reamers, taps, etc. | 2 to 5 | 1 ¼ to 2 | ½ to 1 ¼ |

Table 7a. Standard Shapes and Inch Size Ranges of Grinding Wheels ANSI B74.2-1982

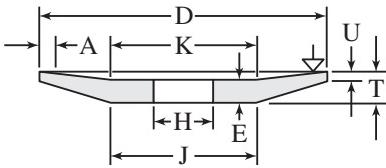
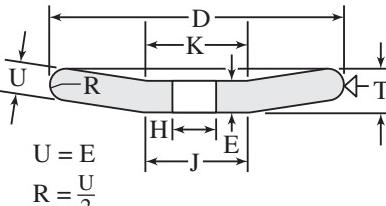
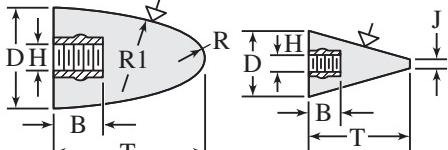
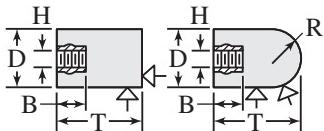
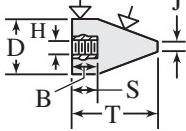
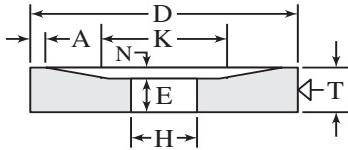
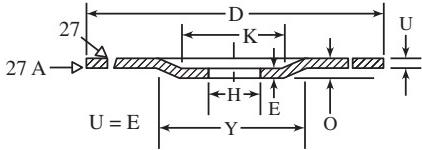
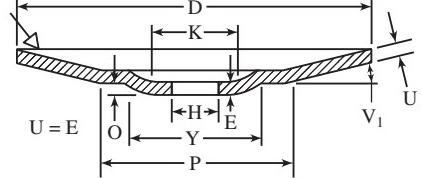
| Applications | Size Ranges of Principal Dimensions, Inches | | |
|---|--|--|--|
| | D = Dia. | T = Thick. | H = Hole |
|  | Type 12. Dish Wheel Grinding on the side or on the U-face of the wheel, the U-face being always present in this type. | | |
| Tool Grinding Broaches, cutters, mills, reamers, taps, etc. | 3 to 8 | $\frac{1}{2}$ or $\frac{3}{4}$ | $\frac{1}{2}$ to $1\frac{1}{4}$ |
|  | Type 13. Saucer Wheel Peripheral grinding wheel, resembling the shape of a saucer, with cross section equal throughout. | | |
| Saw Gumming Saw tooth shaping and sharpening | 8 to 12 | $\frac{1}{2}$ to $1\frac{3}{4}$ $U \& E$ $\frac{1}{4}$ to $1\frac{1}{2}$ | $\frac{3}{4}$ to $1\frac{1}{4}$ |
|  | Type 16. Cone, Curved Side Type 17. Cone, Straight Side, Square Tip Type 17R. Cone, Straight Side, Round Tip (Tip Radius $R = J/2$) | | |
| Snagging, Portable machine, threaded holes | $1\frac{1}{4}$ to 3 | 2 to $3\frac{1}{2}$ | $\frac{3}{8}$ -24UNF-2B to $\frac{5}{8}$ -11UNC-2B |
|  | Type 18. Plug, Square End Type 18R. Plug, Round End $R = D/2$ | | |
|  | Type 19. Plugs, Conical End, Square Tip Type 19R. Plugs, Conical End, Round Tip (Tip Radius $R = J/2$) | | |
| Snagging, Portable machine, threaded holes | $1\frac{1}{4}$ to 3 | 2 to $3\frac{1}{2}$ | $\frac{3}{8}$ -24UNF-2B to $\frac{5}{8}$ -11UNC-2B |
|  | Type 20. Wheel, Relieved One Side Peripheral grinding wheel, one side flat, the other side relieved to a flat. | | |
| Cylindrical Grinding Between centers | 12 to 36 | $\frac{3}{4}$ to 4 | 5 to 20 |

Table 7a. Standard Shapes and Inch Size Ranges of Grinding Wheels ANSI B74.2-1982

| Applications | Size Ranges of Principal Dimensions, Inches <i>D</i> = Dia. <i>T</i> = Thick. <i>H</i> = Hole | | |
|---|---|--------|----------|
| | Type 21. Wheel, Relieved Two Sides Both sides relieved to a flat. | | |
| | Type 22. Wheel, Relieved One Side, Recessed Other Side One side relieved to a flat. | | |
| | Type 23. Wheel, Relieved and Recessed Same Side The other side is straight. | | |
| Cylindrical Grinding Between centers, with wheel periphery | 20 to 36 | 2 to 4 | 12 or 20 |
| | Type 24. Wheel, Relieved and Recessed One Side, Recessed Other Side One side recessed, the other side is relieved to a recess. | | |
| | Type 25. Wheel, Relieved and Recessed One Side, Relieved Other Side One side relieved to a flat, the other side relieved to a recess. | | |
| | Type 26. Wheel, Relieved and Recessed Both Sides | | |
| Cylindrical Grinding Between centers, with the periphery of the wheel | 20 to 36 | 2 to 4 | 12 or 20 |

Table 7a. Standard Shapes and Inch Size Ranges of Grinding Wheels ANSI B74.2-1982

| Applications | Size Ranges of Principal Dimensions, Inches | | |
|---|---|---|--|
| | D = Dia. | T = Thick. | H = Hole |
|  | | | Types 27 & 27A. Wheel, Depressed Center 27. <i>Portable Grinding</i> : Grinding normally done by contact with work at approx. a 15° angle with face of the wheel. 27A. <i>Cutting-off</i> : Using the periphery as grinding face. |
| Cutting Off Reinforced organic bonds only | 16 to 30 | $U = E = \frac{5}{32}$ to $\frac{1}{4}$ | 1 or $1\frac{1}{2}$ |
| Snagging Portable machine | 3 to 9 | $U = \text{Uniform}$ thick. $\frac{1}{8}$ to $\frac{3}{8}$ | $\frac{3}{8}$ or $\frac{7}{8}$ |
|  | | | Type 28. Wheel, Depressed Center (Saucer Shaped Grinding Face) Grinding at approx. 15° angle with wheel face. |
| Snagging Portable machine | 7 or 9 | $U = \text{Uniform}$ thickness $\frac{1}{4}$ | $\frac{7}{8}$ |

Throughout table large open-head arrows indicate grinding surfaces.

Table 7b. Standard Shapes and Metric Size Ranges of Grinding Wheels ANSI B74.2-1982

| Applications | Size Ranges of Principal Dimensions, Millimeters | | |
|--|--|------------|----------------|
| | D = Diam. | T = Thick. | H = Hole |
| Type 1. Straight Wheel | | | |
| Cutting Off (nonreinforced and reinforced organic bonds only) | 150 to 1250 | 0.8 to 10 | 16 to 152.4 |
| Cylindrical Grinding Between centers | 300 to 1250 | 20 to 160 | 127 to 508 |
| Cylindrical Grinding Centerless grinding wheels | 350 to 750 | 25 to 500 | 127 or 304.8 |
| Cylindrical Grinding Centerless regulating wheels | 200 to 350 | 25 to 315 | 76.2 to 152.4 |
| Internal Grinding | 6 to 100 | 6 to 50 | 2.5 to 25 |
| Offhand Grinding on the periphery | | | |
| — General purpose | 150 to 900 | 13 to 100 | 20 to 76.2 |
| — For wet tool grinding only | 750 or 900 | 80 or 100 | 508 |
| Saw Gumming (F-type face) | 150 to 300 | 6 to 40 | 32 |
| Snagging, Floor stand machines | 300 to 600 | 25 to 80 | 32 to 76.2 |
| Snagging, Floor stand machines (organic bond, wheel speed over 33 meters per second) | 500 to 900 | 50 to 100 | 152.4 or 304.8 |

Table 7b. (Continued) Standard Shapes and Metric Size Ranges of Grinding Wheels
ANSI B74.2-1982

| Applications | Size Ranges of Principal Dimensions, Millimeters | | |
|--|---|---------------------------------|--------------------------|
| | D = Diam. | T = Thick. | H = Hole |
| Snagging, Mechanical grinders (organic bond, wheel speed up to 84 meters per second) | 600 | 50 to 80 | 304.8 |
| Snagging, Portable machines | 80 to 200 | 6 to 25 | 10 to 16 |
| Snagging, Swing frame machines (organic bond) | 300 to 600 | 50 to 80 | 88.9 to 304.8 |
| Surface Grinding, Horizontal spindle machines | 150 to 600 | 13 to 160 | 32 to 304.8 |
| Tool Grinding, Broaches, cutters, mills, reamers, taps, etc. | 150 to 250 | 6 to 20 | 32 to 127 |
| Type 2. Cylindrical Wheel | | | <i>W</i> = Wall |
| Surface Grinding, Vertical spindle machines | 200 to 500 | 100 or 125 | 25 to 100 |
| Type 5. Wheel, recessed one side | | | |
| Cylindrical Grinding, Between centers | 300 to 900 | 40 to 100 | 127 or 304.8 |
| Cylindrical Grinding, Centerless regulating wheels | 200 to 350 | 80 to 160 | 76.2 or 127 |
| Internal Grinding | 10 to 100 | 10 to 50 | 3.18 to 25 |
| Type 6. Straight-Cup Wheel | | | <i>W</i> = Wall |
| Snagging, Portable machines, organic bond only (hole is $\frac{5}{8}$ -11 UNC-2B) | 100 to 150 | 50 | 20 to 40 |
| Tool Grinding Broaches, cutters, mills, reamers, taps, etc. (Hole is 13 to 32 mm) | 50 to 150 | 32 to 50 | 8 or 10 |
| Type 7. Wheel, recessed two sides | | | |
| Cylindrical Grinding, Between centers | 300 to 900 | 40 to 100 | 127 or 304.8 |
| Cylindrical Grinding, Centerless regulating wheels | 200 to 350 | 100 to 500 | 76.2 to 152.4 |
| Type 11. Flaring-Cup Wheel | | | |
| Snagging, Portable machines, organic bonds only, threaded hole | 100 to 150 | 50 | $\frac{5}{8}$ -11 UNC-2B |
| Tool Grinding Broaches, cutters, mills, reamers, taps, etc. | 50 to 125 | 32 to 50 | 13 to 32 |
| Type 12. Dish Wheel | | | |
| Tool Grinding Broaches, cutters, mills, reamers, taps, etc. | 80 to 200 | 13 or 20 | 13 to 32 |
| Type 27 and 27A. Wheel, depressed center | | | |
| Cutting Off Reinforced organic bonds only | 400 to 750 | <i>U</i> = <i>E</i> = 6 | 25.4 or 38.1 |
| Snagging Portable machines | 80 to 230 | <i>U</i> = <i>E</i> = 3.2 to 10 | 9.53 or 22.23 |

All dimensions in millimeters.

See Table 7a for diagrams and descriptions of each wheel type.

The operating surface of the grinding wheel is often referred to as the wheel face. In the majority of cases it is the periphery of the grinding wheel which, when not specified otherwise, has a straight profile. However, other face shapes can also be supplied by the grinding wheel manufacturers, and also reproduced during usage by appropriate truing. ANSI B74.2-1982 standard offers 15 different shapes for grinding wheel faces, which are shown in Table 8.

Table 8. Standard Shapes of Grinding Wheel Faces ANSI B74.2-1982

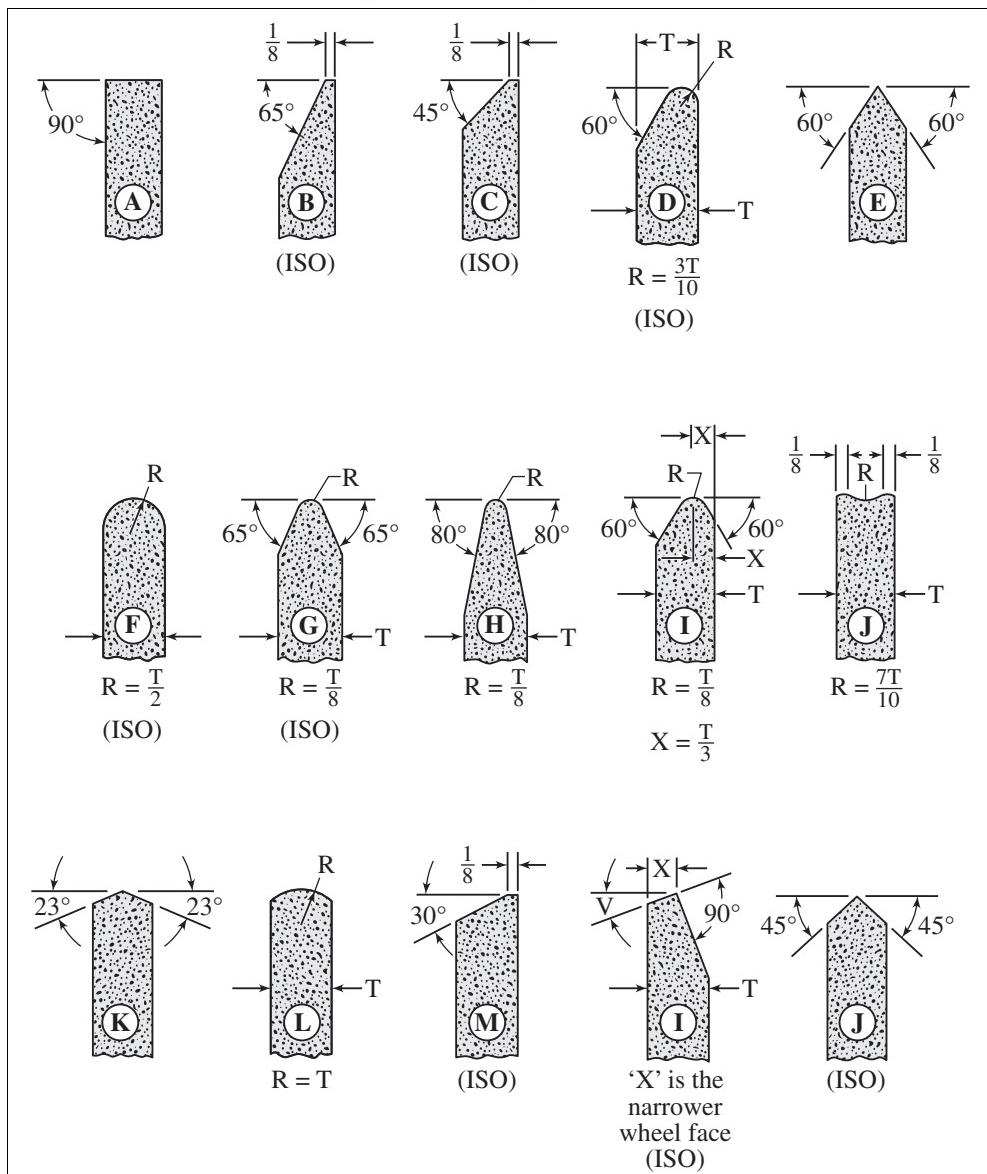


Table 9. Diamond Wheel Core Shapes and Designations ANSI B74.3-1974

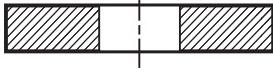
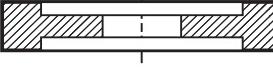
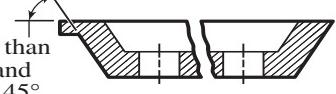
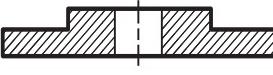
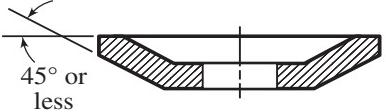
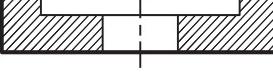
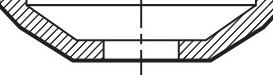
| | | | |
|---|---|--|----|
|  | 1 |  | 9 |
|  | 2 |  Less than 90° and over 45° | 11 |
|  | 3 |  45° or less | 12 |
|  | 4 |  | 14 |
|  | 6 |  | 15 |

Table 10. Diamond Wheel Cross-sections and Designations

ANSI B74.3-1974

| | | | | | | | | | | | |
|---|----|---|----|---|----|---|----|---|----|--|---|
|  | A |  | CH |  | ER |  | GN |  | LL |  | S |
|  | AH |  | D |  | ET |  | H |  | M |  | U |
|  | B |  | DD |  | F |  | J |  | P |  | V |
|  | BT |  | E |  | FF |  | K |  | Q |  | Y |
|  | C |  | EE |  | G |  | L |  | QQ | | |

Table 11. Designations for Location of Diamond Section on Diamond Wheel ANSI B74.3-1974

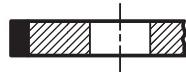
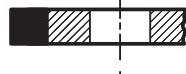
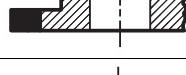
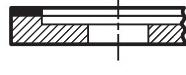
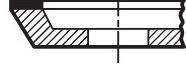
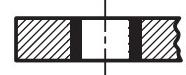
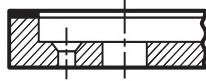
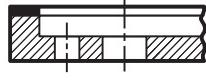
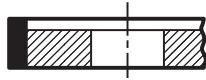
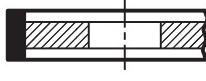
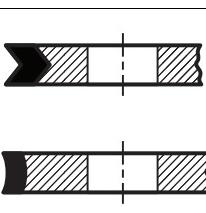
| Designation No. and Location | Description | Illustration |
|------------------------------|---|--|
| 1 — Periphery | The diamond section shall be placed on the periphery of the core and shall extend the full thickness of the wheel. The axial length of this section may be greater than, equal to, or less than the depth of diamond, measured radially. A hub or hubs shall not be considered as part of the wheel thickness for this definition. |    |
| 2 — Side | The diamond section shall be placed on the side of the wheel and the length of the diamond section shall extend from the periphery toward the center. It may or may not include the entire side and shall be greater than the diamond depth measured axially. It shall be on the side of the wheel that is commonly used for grinding purposes. |   |
| 3 — Both Sides | The diamond sections shall be placed on both sides of the wheel and shall extend from the periphery toward the center. They may or may not include the entire sides, and the radial length of the diamond section shall exceed the axial diamond depth. |  |
| 4 — Inside Bevel or Arc | This designation shall apply to the general wheel types 2, 6, 11, 12, and 15 and shall locate the diamond section on the side wall. This wall shall have an angle or arc extending from a higher point at the wheel periphery to a lower point toward the wheel center |  |
| 5 — Outside Bevel or Arc | This designation shall apply to the general wheel types, 2, 6, 11, and 15 and shall locate the diamond section on the side wall. This wall shall have an angle or arc extending from a lower point at the wheel periphery to a higher point toward the wheel center. |  |
| 6 — Part of Periphery | The diamond section shall be placed on the periphery of the core but shall not extend the full thickness of the wheel and shall not reach to either side |   |
| 7 — Part of Side | The diamond section shall be placed on the side of the core and shall not extend to the wheel periphery. It may or may not extend to the center. |  |
| 8 — Throughout | Designates wheels of solid diamond abrasive section without cores. |  |
| 9 — Corner | Designates a location that would commonly be considered to be on the periphery except that the diamond section shall be on the corner but shall not extend to the other corner. |  |
| 10 — Annular | Designates a location of the diamond abrasive section on the inner annular surface of the wheel. |  |

Table 12. Designation Letters for Modifications of Diamond Wheels
ANSI B74.3-1974

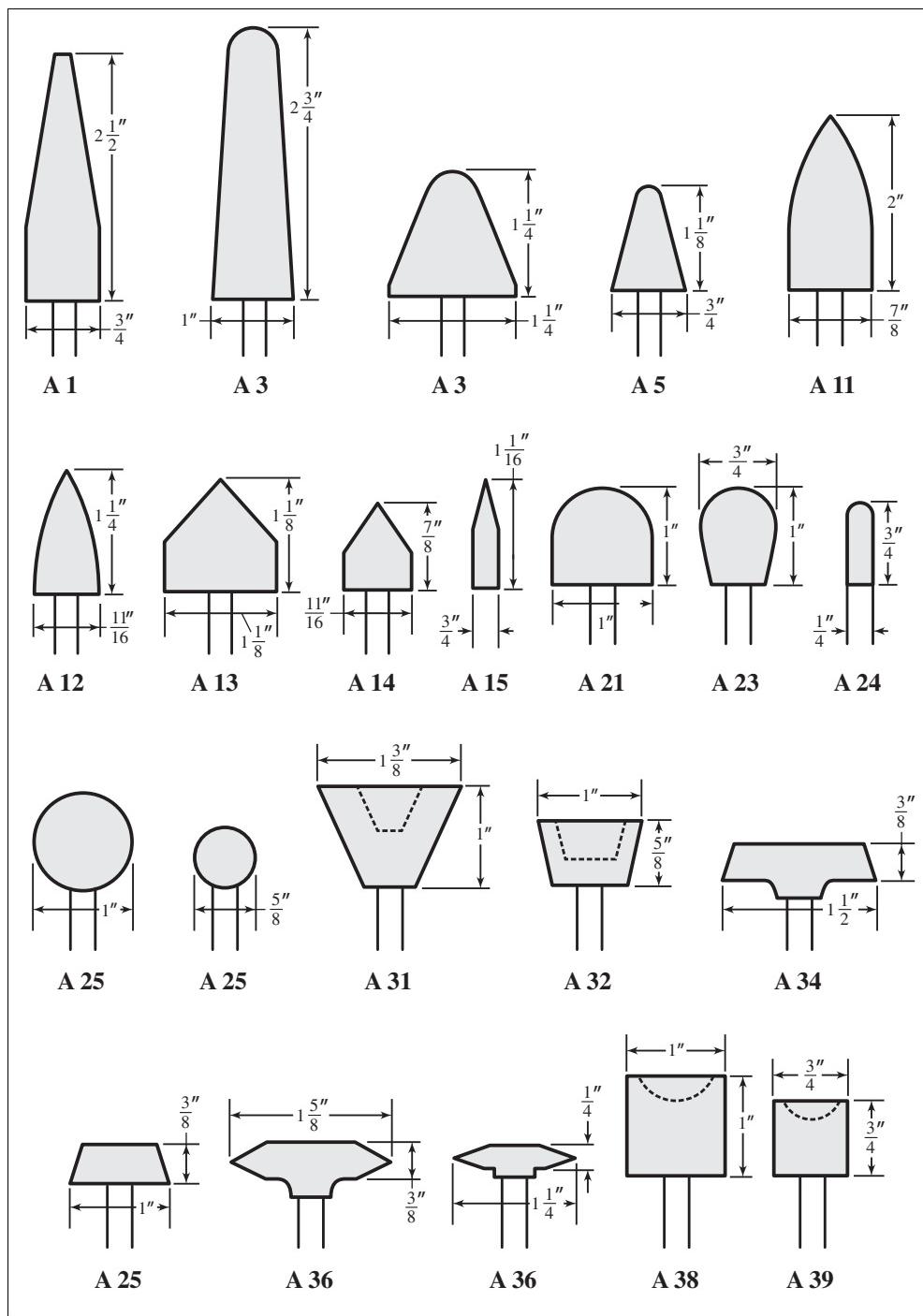
| Designation Letter ^a | Description | Illustration |
|---------------------------------|---|--|
| B — Drilled and Counterbored | Holes drilled and counterbored in core. |  |
| C — Drilled and Countersunk | Holes drilled and countersunk in core. |  |
| H — Plain Hole | Straight hole drilled in core. |  |
| M — Holes Plain and Threaded | Mixed holes, some plain, some threaded, are in core. |  |
| P — Relieved One Side | Core relieved on one side of wheel. Thickness of core is less than wheel thickness. |  |
| R — Relieved Two Sides | Core relieved on both sides of wheel. Thickness of core is less than wheel thickness. |  |
| S — Segmented Diamond Section | Wheel has segmental diamond section mounted on core. (Clearance between segments has no bearing on definition.) |  |
| SS — Segmental and Slotted | Wheel has separated segments mounted on a slotted core. |  |
| T — Threaded Holes | Threaded holes are in core. |  |
| Q — Diamond Inserted | Three surfaces of the diamond section are partially or completely enclosed by the core. |  |
| V — Diamond Inverted | Any diamond cross section, which is mounted on the core so that the interior point of any angle, or the concave side of any arc, is exposed shall be considered inverted. <i>Exception:</i> Diamond cross section AH shall be placed on the core with the concave side of the arc exposed. |  |

^aY — Diamond Inserted and Inverted. See definitions for Q and V.

**Table 13. General Diamond Wheel Recommendations
for Wheel Type and Abrasive Specification**

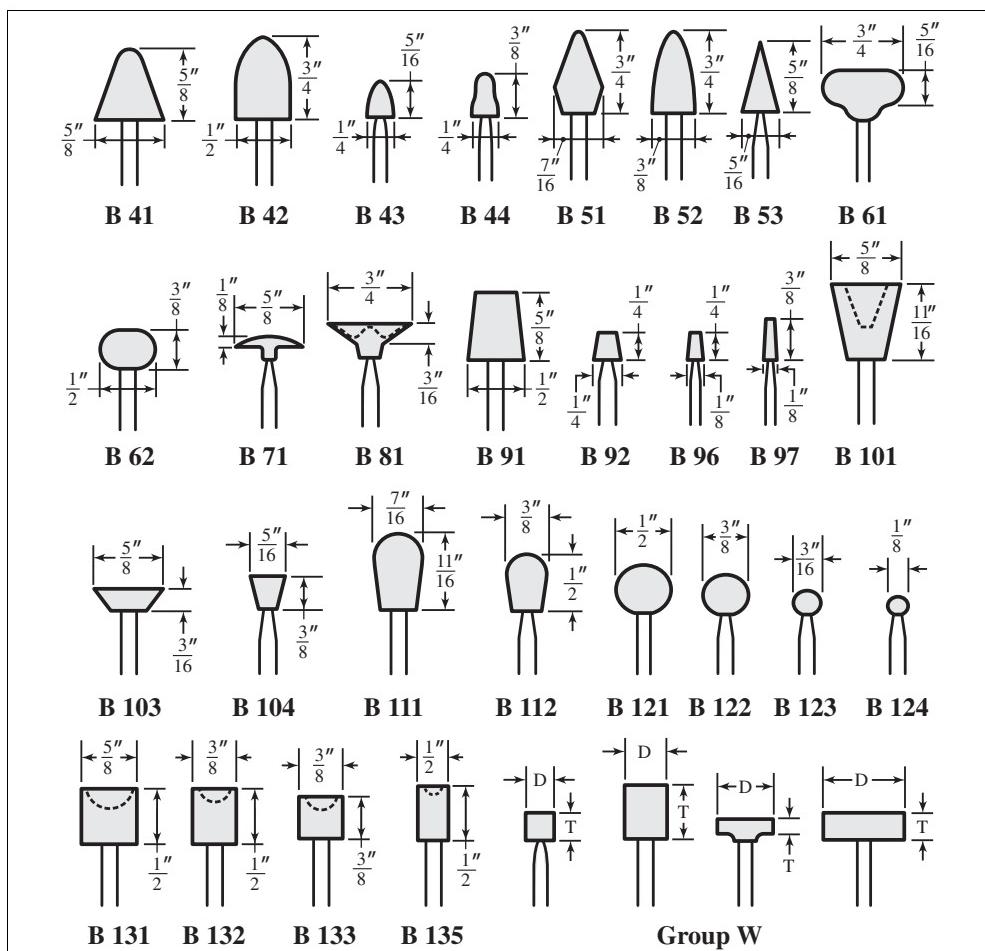
| Typical Applications or Operation | Basic Wheel Type | Abrasive Specification | |
|--|------------------|---|----------------------------|
| Single Point Tools (offhand grinding) | D6A2C | <i>Rough:</i> MD100-N100-B $\frac{1}{8}$ <i>Finish:</i> MD220-P75-B $\frac{1}{8}$ | |
| Single Point Tools (machine ground) | D6A2H | <i>Rough:</i> MD180-J100-B $\frac{1}{8}$ <i>Finish:</i> MD320-L75-B $\frac{1}{8}$ | |
| Chip Breakers | D1A1 | | MD150-R100-B $\frac{1}{8}$ |
| Multitooth Tools and Cutters (face mills, end mills, reamers, broaches, etc.) Sharpening and Backing off | D11V9 | <i>Rough:</i> MD100-R100-B $\frac{1}{8}$ <i>Combination:</i> MD150-R100-B $\frac{1}{8}$ <i>Finish:</i> MD220-R100-B $\frac{1}{8}$ | |
| Multitooth Tools and Cutters (face mills, end mills, reamers, broaches, etc.) Fluting | D12A2 | | MD180-N100-B $\frac{1}{8}$ |
| Saw Sharpening | D12A2 | | MD180-R100-B $\frac{1}{8}$ |
| Surface Grinding (horizontal spindle) | D1A1 | <i>Rough:</i> MD120-N100-B $\frac{1}{8}$ <i>Finish:</i> MD240-P100-B $\frac{1}{8}$ | |
| Surface Grinding (vertical spindle) | D2A2T | | MD80-R75-B $\frac{1}{8}$ |
| Cylindrical or Centertype Grinding | D1A1 | | MD120-P100-B $\frac{1}{8}$ |
| Internal Grinding | D1A1 | | MD150-N100-B $\frac{1}{8}$ |
| Slotting and Cutoff | D1A1R | | MD150-R100-B $\frac{1}{4}$ |
| Lapping | Disc | | MD400-L50-B $\frac{1}{16}$ |
| Hand Honing | DH1, DH2 | <i>Rough:</i> MD220-B $\frac{1}{16}$ <i>Finish:</i> MD320-B $\frac{1}{16}$ | |

Table 14a. Standard Shapes and Inch Sizes of Mounted Wheels and Points
ANSI B74.2-1982



The maximum speeds of mounted vitrified wheels and points of average grade range from about 38,000 to 152,000 rpm for diameters of 1 inch down to $\frac{1}{4}$ inch. However, the safe operating speed usually is limited by the critical speed (speed at which vibration or whip tends to become excessive) which varies according to wheel or point dimensions, spindle diameter, and overhang.

Table 14b. Standard Shapes and Inch Sizes of Mounted Wheels and Points
ANSI B74.2-1982



| Abrasive Shape No. | Abrasive Shape Size | | Abrasive Shape No. | Abrasive Shape Size | | Abrasive Shape No. | Abrasive Shape Size | |
|--------------------|---------------------|-------|--------------------|---------------------|-------|--------------------|---------------------|-------|
| | D | T | | D | T | | D | T |
| W 144 | 1/8 | 1/4 | W 182 | 1/2 | 1/8 | W 208 | 3/4 | 2 |
| W 145 | 1/8 | 3/8 | W 183 | 1/2 | 1/4 | W 215 | 1 | 1/8 |
| W 146 | 1/8 | 1/2 | W 184 | 1/2 | 3/8 | W 216 | 1 | 1/4 |
| W 152 | 3/16 | 1/4 | W 185 | 1/2 | 1/2 | W 217 | 1 | 3/8 |
| W 153 | 3/16 | 3/8 | W 186 | 1/2 | 3/4 | W 218 | 1 | 1/2 |
| W 154 | 3/16 | 1/2 | W 187 | 1/2 | 1 | W 220 | 1 | 1 |
| W 158 | 1/4 | 1/8 | W 188 | 1/2 | 1 1/2 | W 221 | 1 | 1 1/2 |
| W 160 | 1/4 | 1/4 | W 189 | 1/2 | 2 | W 222 | 1 | 2 |
| W 162 | 1/4 | 3/8 | W 195 | 5/8 | 3/4 | W 225 | 1 1/4 | 1/4 |
| W 163 | 1/4 | 1/2 | W 196 | 5/8 | 1 | W 226 | 1 1/4 | 3/8 |
| W 164 | 1/4 | 3/4 | W 197 | 5/8 | 2 | W 228 | 1 1/4 | 3/4 |
| W 174 | 3/8 | 1/4 | W 200 | 3/4 | 1/8 | W 230 | 1 1/4 | 1 1/4 |
| W 175 | 3/8 | 3/8 | W 201 | 3/4 | 1/4 | W 232 | 1 1/4 | 2 |
| W 176 | 3/8 | 1/2 | W 202 | 3/4 | 3/8 | W 235 | 1 1/2 | 1/4 |
| W 177 | 3/8 | 3/4 | W 203 | 3/4 | 1/2 | W 236 | 1 1/2 | 1/2 |
| W 178 | 3/8 | 1 | W 204 | 3/4 | 3/4 | W 237 | 1 1/2 | 1 |
| W 179 | 3/8 | 1 1/4 | W 205 | 3/4 | 1 | W 238 | 1 1/2 | 1 1/2 |
| W 181 | 1/2 | 1/16 | W 207 | 3/4 | 1 1/2 | W 242 | 2 | 1 |

**Table 15. Standard Shapes and Metric Sizes of
Mounted Wheels and Points ANSI B74.2-1982**

| Abrasive Shape No. ^a | Abrasive Shape Size | | Abrasive Shape No. ^a | Abrasive Shape Size | |
|---------------------------------|---------------------|-----------|---------------------------------|---------------------|-----------|
| | Diameter | Thickness | | Diameter | Thickness |
| A 1 | 20 | 65 | A 24 | 6 | 20 |
| A 3 | 22 | 70 | A 25 | 25 | ... |
| A 4 | 30 | 30 | A 26 | 16 | ... |
| A 5 | 20 | 28 | A 31 | 35 | 26 |
| A 11 | 21 | 45 | A 32 | 25 | 20 |
| A 12 | 18 | 30 | A 34 | 38 | 10 |
| A 13 | 25 | 25 | A 35 | 25 | 10 |
| A 14 | 18 | 22 | A 36 | 40 | 10 |
| A 15 | 6 | 25 | A 37 | 30 | 6 |
| A 21 | 25 | 25 | A 38 | 25 | 25 |
| A 23 | 20 | 25 | A 39 | 20 | 20 |
| B 41 | 16 | 16 | B 97 | 3 | 10 |
| B 42 | 13 | 20 | B 101 | 16 | 18 |
| B 43 | 6 | 8 | B 103 | 16 | 5 |
| B 44 | 5.6 | 10 | B 104 | 8 | 10 |
| B 51 | 11 | 20 | B 111 | 11 | 18 |
| B 52 | 10 | 20 | B 112 | 10 | 13 |
| B 53 | 8 | 16 | B 121 | 13 | ... |
| B 61 | 20 | 8 | B 122 | 10 | ... |
| B 62 | 13 | 10 | B 123 | 5 | ... |
| B 71 | 16 | 3 | B 124 | 3 | ... |
| B 81 | 20 | 5 | B 131 | 13 | 13 |
| B 91 | 13 | 16 | B 132 | 10 | 13 |
| B 92 | 6 | 6 | B 133 | 10 | 10 |
| B 96 | 3 | 6 | B 135 | 6 | 13 |
| W 144 | 3 | 6 | W 196 | 16 | 26 |
| W 145 | 3 | 10 | W 197 | 16 | 50 |
| W 146 | 3 | 13 | W 200 | 20 | 3 |
| W 152 | 5 | 6 | W 201 | 20 | 6 |
| W 153 | 5 | 10 | W 202 | 20 | 10 |
| W 154 | 5 | 13 | W 203 | 20 | 13 |
| W 158 | 6 | 3 | W 204 | 20 | 20 |
| W 160 | 6 | 6 | W 205 | 20 | 25 |
| W 162 | 6 | 10 | W 207 | 20 | 40 |
| W 163 | 6 | 13 | W 208 | 20 | 50 |
| W 164 | 6 | 20 | W 215 | 25 | 3 |
| W 174 | 10 | 6 | W 216 | 25 | 6 |
| W 175 | 10 | 10 | W 217 | 25 | 10 |
| W 176 | 10 | 13 | W 218 | 25 | 13 |
| W 177 | 10 | 20 | W 220 | 25 | 25 |
| W 178 | 10 | 25 | W 221 | 25 | 40 |
| W 179 | 10 | 30 | W 222 | 25 | 50 |
| W 181 | 13 | 1.5 | W 225 | 30 | 6 |
| W 182 | 13 | 3 | W 226 | 30 | 10 |
| W 183 | 13 | 6 | W 228 | 30 | 20 |
| W 184 | 13 | 10 | W 230 | 30 | 30 |
| W 185 | 13 | 13 | W 232 | 30 | 50 |
| W 186 | 13 | 20 | W 235 | 40 | 6 |
| W 187 | 13 | 25 | W 236 | 40 | 13 |
| W 188 | 13 | 40 | W 237 | 40 | 25 |
| W 189 | 13 | 50 | W 238 | 40 | 40 |
| W 195 | 16 | 20 | W 242 | 50 | 25 |

^a See shape diagrams on pages 223 and 224.

All dimensions are in millimeters.

Table 16. Lapping Lubricants

| Lubricant | Use |
|--------------------------|--|
| Lard Oil and Machine Oil | Machine and lard oil are the best lubricants for use with copper and steel laps, but the least effective with a cast-iron lap. Lard oil gives the higher rate of cutting. In general, the initial rate of cutting is higher with machine oil, but falls off more rapidly as work continues. With lard oil, the highest results are obtained with a carborundum-charged steel lap. Lowest results were obtained with machine oil when using an emery-charged, cast-iron lap. |
| Gasoline and Kerosene | Gasoline and kerosene are the best lubricants for use with cast- iron laps, and the poorest on steel. Gasoline is superior to any lubricant tested on cast-iron laps. Kerosene is used with rotary diamond lap for finishing very small holes. Values obtained with carborundum were higher than those obtained with emery, except when used on a copper lap. |
| Turpentine | Turpentine was found to work well with carborundum on any lap; work fair with emery on copper laps; but was inferior with emery on cast-iron and steel laps. |
| Soda Water | Medium results with any combination of abrasives; best on copper and poorest on steel. Better than machine or lard oil on cast iron, but not so good as gasoline or kerosene. Highest result when used with aluminium on copper lap. |

Notes. The initial rate of cutting does not greatly differ for different abrasives. There is no advantage in using an abrasive coarser than No. 150. The rate of cutting is practically proportional to the pressure.

Sharpening Carbide Tools.—Cemented carbide indexable inserts are usually not resharpened but sometimes they require a special grind in order to form a contour on the cutting edge to suit a special purpose. Brazed type carbide cutting tools are resharpened after the cutting edge has become worn. On brazed carbide tools the cutting-edge wear should not be allowed to become excessive before the tool is re-sharpened. One method of determining when brazed carbide tools need resharpening is by periodic inspection of the flank wear and the condition of the face. Another method is to determine the amount of production which is normally obtained before excessive wear has taken place, or to determine the equivalent period of time. One disadvantage of this method is that slight variations in the work material will often cause the wear rate not to be uniform and the number of parts machined before regrounding will not be the same each time. Usually, sharpening should not require the removal of more than 0.005 to 0.010 inch of carbide.

General Procedure in Carbide Tool Grinding: The general procedure depends upon the kind of grinding operation required. If the operation is to resharpen a dull tool, a diamond wheel of 100 to 120 grain size is recommended although a finer wheel—up to 150 grain size—is sometimes used to obtain a better finish. If the tool is new or is a “standard” design and changes in shape are necessary, a 100-grit diamond wheel is recommended for roughing and a finer grit diamond wheel can be used for finishing. Some shops prefer to rough grind the carbide with a vitrified silicon carbide wheel, the finish grinding being done with a diamond wheel. A final operation commonly designated as lapping may or may not be employed for obtaining an extra-fine finish.

Wheel Speeds: The speed of silicon carbide wheels usually is about 5000 feet per minute. The speeds of diamond wheels generally range from 5000 to 6000 feet per minute; yet lower speeds (550 to 3000 fpm) can be effective.

Offhand Grinding: In grinding single-point tools (excepting chip breakers) the common practice is to hold the tool by hand, press it against the wheel face and traverse it continuously across the wheel face while the tool is supported on the machine rest or table which is adjusted to the required angle. This is known as “offhand grinding” to distinguish it from the machine grinding of cutters as in regular cutter grinding practice. The selection of wheels adapted to carbide tool grinding is very important.

Silicon Carbide Wheels.—The green colored silicon carbide wheels generally are preferred to the dark gray or gray-black variety, although the latter are sometimes used.

Grain or Grit Sizes: For roughing, a grain size of 60 is very generally used. For finish grinding with silicon carbide wheels, a finer grain size of 100 or 120 is common. A silicon carbide wheel such as C60-I-7V may be used for grinding both the steel shank and carbide tip. However, for under-cutting steel shanks up to the carbide tip, it may be advantageous to use an aluminum oxide wheel suitable for grinding softer, carbon steel.

Grade: According to the standard system of marking, different grades from soft to hard are indicated by letters from A to Z. For carbide tool grinding fairly soft grades such as G, H, I, and J are used. The usual grades for roughing are I or J and for finishing H, I, and J. The grade should be such that a sharp free-cutting wheel will be maintained without excessive grinding pressure. Harder grades than those indicated tend to overheat and crack the carbide.

Structure: The common structure numbers for carbide tool grinding are 7 and 8. The larger cup-wheels (10 to 14 inches) may be of the porous type and be designated as 12P. The standard structure numbers range from 1 to 15 with progressively higher numbers indicating less density and more open wheel structure.

Diamond Wheels.—Wheels with diamond-impregnated grinding faces are fast and cool cutting and have a very low rate of wear. They are used extensively both for resharpening and for finish grinding of carbide tools when preliminary roughing is required. Diamond wheels are also adapted for sharpening multi-tooth cutters such as milling cutters and reamers, which are ground in a cutter grinding machine.

Resinoid bonded wheels are commonly used for grinding chip breakers, milling cutters, reamers or other multi-tooth cutters. They are also applicable to precision grinding of carbide dies, gages, and various external, internal and surface grinding operations. Fast, cool cutting action is characteristic of these wheels.

Metal bonded wheels are often used for offhand grinding of single-point tools especially when durability or long life and resistance to grooving of the cutting face, are considered more important than the rate of cutting. *Vitrified bonded* wheels are used both for roughing of chipped or very dull tools and for ordinary resharpening and finishing. They provide rigidity for precision grinding, a porous structure for fast cool cutting, sharp cutting action and durability.

Diamond Wheel Grit Sizes.—For roughing with diamond wheels a grit size of 100 is the most common both for offhand and machine grinding.

Grit sizes of 120 and 150 are frequently used in offhand grinding of single point tools 1) for resharpening; 2) for a combination roughing and finishing wheel; and 3) for chip-breaker grinding.

Grit sizes of 220 or 240 are used for ordinary finish grinding all types of tools (offhand and machine) and also for cylindrical, internal and surface finish grinding. Grits of 320 and 400 are used for "lapping" to obtain very fine finishes, and for hand hones. A grit of 500 is for lapping to a mirror finish on such work as carbide gages and boring or other tools for exceptionally fine finishes.

Diamond Wheel Grades.—Diamond wheels are made in several different grades to better adapt them to different classes of work. The grades vary for different types and shapes of wheels. Standard Norton grades are H, J, and L, for resinoid bonded wheels, grade N for metal bonded wheels and grades J, L, N, and P, for vitrified wheels. Harder and softer grades than standard may at times be used to advantage.

Diamond Concentration.—The relative amount (by carat weight) of diamond in the diamond section of the wheel is known as the "diamond concentration." Concentrations of 100 (high), 50 (medium) and 25 (low) ordinarily are supplied. A concentration of 50 repre-

sents one-half the diamond content of 100 (if the depth of the diamond is the same in each). and 25 equals one-fourth the content of 100 or one-half the content of 50 concentration.

100 Concentration: Generally interpreted to mean 72 carats of diamond/in.³ of abrasive section. (A 75 concentration indicates 54 carats/in.³.) Recommended (especially in grit sizes up to about 220) for general machine grinding of carbides, and for grinding cutters and chip breakers. Vitrified and metal bonded wheels usually have 100 concentration.

50 Concentration: In the finer grit sizes of 220, 240, 320, 400, and 500, a 50 concentration is recommended for offhand grinding with resinoid bonded cup-wheels.

25 Concentration: A low concentration of 25 is recommended for offhand grinding with resinoid bonded cup-wheels with grit sizes of 100, 120 and 150.

Depth of Diamond Section: The radial depth of the diamond section usually varies from $\frac{1}{16}$ to $\frac{1}{4}$ inch. The depth varies somewhat according to the wheel size and type of bond.

Dry Versus Wet Grinding of Carbide Tools.—In using silicon carbide wheels, grinding should be done either absolutely dry or with enough coolant to flood the wheel and tool. Satisfactory results may be obtained either by the wet or dry method. However, dry grinding is the most prevalent usually because, in wet grinding, operators tend to use an inadequate supply of coolant to obtain better visibility of the grinding operation and avoid getting wet; hence checking or cracking is more likely to occur in wet grinding than in dry grinding.

Wet Grinding with Silicon Carbide Wheels: One advantage commonly cited in connection with wet grinding is that an ample supply of coolant permits using wheels about one grade harder than in dry grinding thus increasing the wheel life. Plenty of coolant also prevents thermal stresses and the resulting cracks, and there is less tendency for the wheel to load. A dust exhaust system also is unnecessary.

Wet Grinding with Diamond Wheels: In grinding with diamond wheels the general practice is to use a coolant to keep the wheel face clean and promote free cutting. The amount of coolant may vary from a small stream to a coating applied to the wheel face by a felt pad.

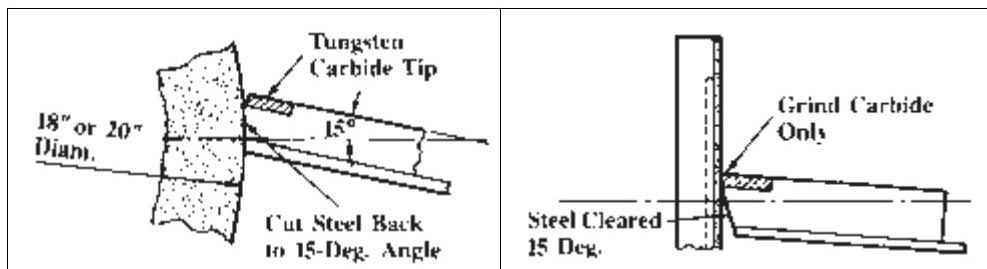
Coolants for Carbide Tool Grinding.—In grinding either with silicon carbide or diamond wheels a coolant that is used extensively consists of water plus a small amount either of soluble oil, sal soda, or soda ash to prevent corrosion. One prominent manufacturer recommends for silicon carbide wheels about 1 ounce of soda ash per gallon of water and for diamond wheels, kerosene. The use of kerosene is quite general for diamond wheels and usually it is applied to the wheel face by a felt pad. Another coolant recommended for diamond wheels consists of 80 per cent water and 20 per cent soluble oil.

Peripheral Versus Flat Side Grinding.—In grinding single point carbide tools with silicon carbide wheels, the roughing preparatory to finishing with diamond wheels may be done either by using the flat face of a cup-shaped wheel (side grinding) or the periphery of a "straight" or disk-shaped wheel. Even where side grinding is preferred, the periphery of a straight wheel may be used for heavy roughing as in grinding back chipped or broken tools (see left-hand diagram). Reasons for preferring peripheral grinding include faster cutting with less danger of localized heating and checking especially in grinding broad surfaces. The advantages usually claimed for side grinding are that proper rake or relief angles are easier to obtain and the relief or land is ground flat. The diamond wheels used for tool sharpening are designed for side grinding. (See right-hand diagram.)

Lapping Carbide Tools.—Carbide tools may be finished by lapping, especially if an exceptionally fine finish is required on the work as, for example, tools used for precision boring or turning non-ferrous metals. If the finishing is done by using a diamond wheel of very fine grit (such as 240, 320, or 400), the operation is often called "lapping." A second lapping method is by means of a power-driven lapping disk charged with diamond dust, Norbide powder, or silicon carbide finishing compound. A third method is by using a hand lap or hone usually of 320 or 400 grit. In many plants the finishes obtained with carbide

tools meet requirements without a special lapping operation. Any feather edge which may be left on tools should be always removed and it is good practice to bevel the edges of roughing tools at 45 degrees to leave a chamfer 0.005 to 0.010 inch wide. This is done by hand honing and the object is to prevent crumbling or flaking off at the edges when hard scale or heavy chip pressure is encountered.

Hand Honing: The cutting edge of carbide tools, and tools made from other tool materials, is sometimes hand honed before it is used in order to strengthen the cutting edge. When interrupted cuts or heavy roughing cuts are to be taken, or when the grade of carbide is slightly too hard, hand honing is beneficial because it will prevent chipping, or even possibly, breakage of the cutting edge. Whenever chipping is encountered, hand honing the cutting edge before use will be helpful. It is important, however, to hone the edge lightly and only when necessary. Heavy honing will always cause a reduction in tool life. Normally, removing 0.002 to 0.004 inch from the cutting edge is sufficient. When indexable inserts are used, the use of pre-honed inserts is preferred to hand honing although sometimes an additional amount of honing is required. Hand honing of carbide tools in between cuts is sometimes done to defer grinding or to increase the life of a cutting edge on an indexable insert. If correctly done, so as not to change the relief angle, this procedure is sometimes helpful. If improperly done, it can result in a reduction in tool life.

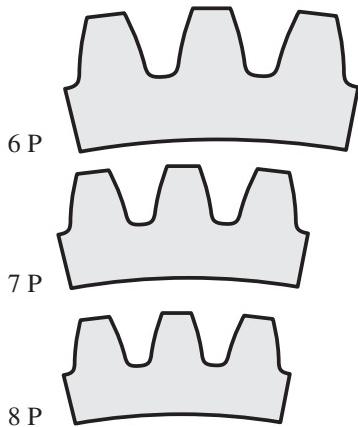


Chip Breaker Grinding.—For this operation a straight diamond wheel is used on a universal tool and cutter grinder, a small surface grinder, or a special chipbreaker grinder. A resinoid bonded wheel of the grade J or N commonly is used and the tool is held rigidly in an adjustable holder or vise. The width of the diamond wheel usually varies from $\frac{1}{8}$ to $\frac{1}{4}$ inch. A vitrified bond may be used for wheels as thick as $\frac{1}{4}$ inch, and a resinoid bond for relatively narrow wheels.

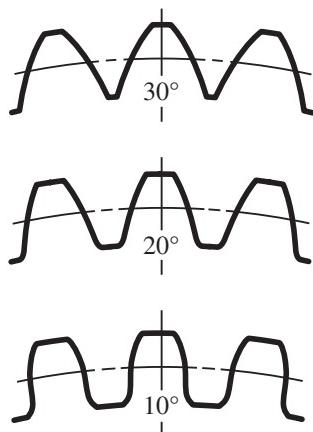
Summary of Miscellaneous Points.—In grinding a single-point carbide tool, traverse it across the wheel face continuously to avoid localized heating. This traverse movement should be quite rapid in using silicon carbide wheels and comparatively slow with diamond wheels. A hand traversing and feeding movement, whenever practicable, is generally recommended because of greater sensitivity. In grinding, maintain a constant, moderate pressure. Manipulating the tool so as to keep the contact area with the wheel as small as possible will reduce heating and increase the rate of stock removal. Never cool a hot tool by dipping it in a liquid, as this may crack the tip. Wheel rotation should preferably be *against* the cutting edge or from the front face toward the back. If the grinder is driven by a reversing motor, opposite sides of a cup wheel can be used for grinding right-and left-hand tools and with rotation against the cutting edge. If it is necessary to grind the top face of a single-point tool, this should precede the grinding of the side and front relief, and top-face grinding should be minimized to maintain the tip thickness. In machine grinding with a diamond wheel, limit the feed per traverse to 0.001 inch for 100 to 120 grit; 0.0005 inch for 150 to 240 grit; and 0.0002 inch for 320 grit and finer.

GEARING

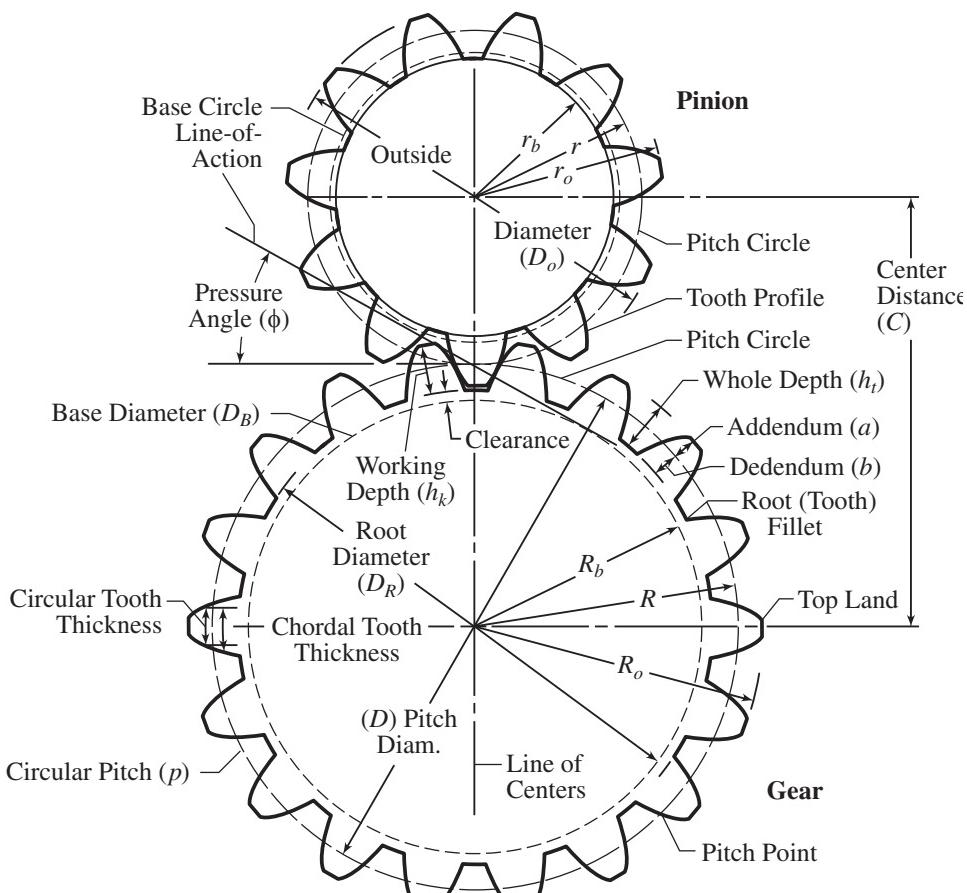
Nomenclature and Comparative Sizes of Gear Teeth



Gear Teeth of Different Diametral Pitch, Full Size

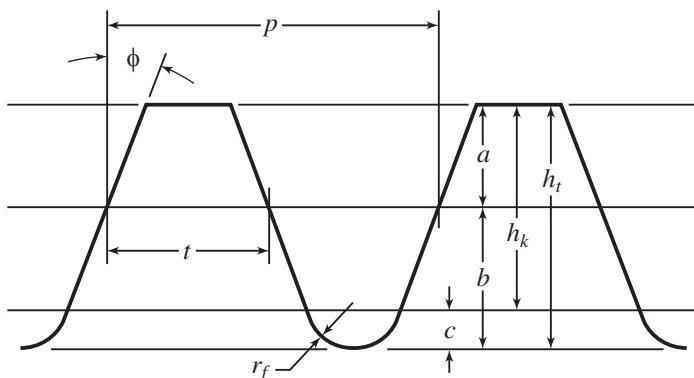


Shapes of Gear Teeth of Different Pressure Angles



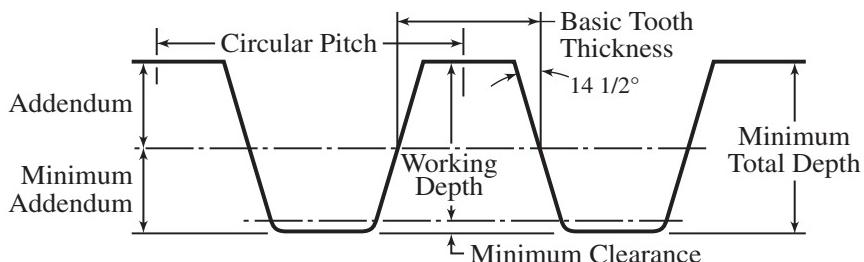
Terms Used in Gear Geometry from Table 1 on page 232

American National Standard and Former American Standard Gear Tooth Forms
ANSI B6.1-1968, R1974 and ASA B6.1-1932

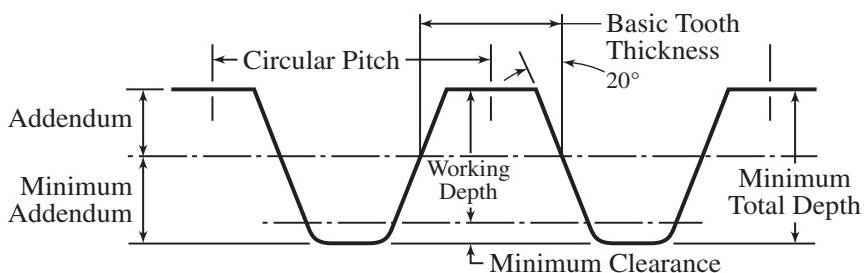


a = addendum h_k = working depth r_f = fillet radius of basic rack
 b = dedendum h_t = whole depth t = circular tooth thickness — basic
 c = clearance p = circular pitch ϕ = pressure angle

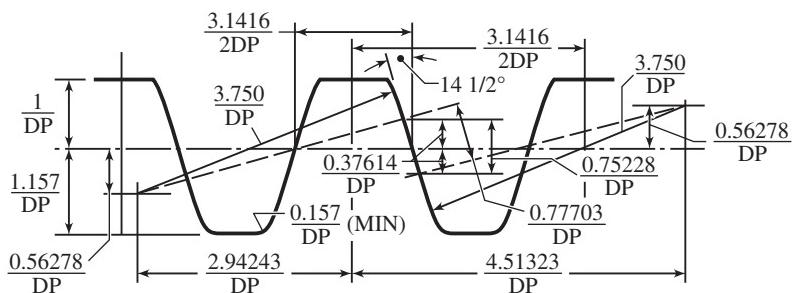
Basic Rack of the 20-Degree and 25-Degree Full-Depth Involute Systems



Basic Rack of the 14½-Degree Full-Depth Involute System



Basic Rack of the 20-Degree Stub Involute System



Approximation of Basic Rack for the 14½-Degree Composite System

Table 1. Formulas for Dimensions of Standard Spur Gears

| No. | To Find | Formula | No. | To Find | Formula |
|------------------|----------------------|-----------------------------------|-----|---|-----------------------------------|
| General Formulas | | | | | |
| 1 | Base Circle Diameter | $D_B = D \cos\phi$ | 6a | Number of Teeth | $N = P \times D$ |
| 2a | Circular Pitch | $p = \frac{3.1416D}{N}$ | 6b | Number of Teeth | $N = \frac{3.1416D}{p}$ |
| 2b | Circular Pitch | $p = \frac{3.1416}{P}$ | 7a | Outside Diameter (Full-depth Teeth) | $D_O = \frac{N+2}{P}$ |
| 3a | Center Distance | $C = \frac{N_P(m_G + 1)}{2P}$ | 7b | Outside Diameter (Full-depth Teeth) | $D_O = \frac{(N+2)p}{3.1416}$ |
| 3b | Center Distance | $C = \frac{D_P + D_G}{2}$ | 8a | Outside Diameter (Amer. Stnd. Stub Teeth) | $D_O = \frac{N + 1.6}{P}$ |
| 3c | Center Distance | $C = \frac{N_G + N_P}{2P}$ | 8b | Outside Diameter (Amer. Stnd. Stub Teeth) | $D_O = \frac{(N + 1.6)p}{3.1416}$ |
| 3d | Center Distance | $C = \frac{(N_G + N_P)p}{6.2832}$ | 9 | Outside Diameter | $D_O = D + 2a$ |
| 4a | Diametral Pitch | $P = \frac{3.1416}{p}$ | 10a | Pitch Diameter | $D = \frac{N}{P}$ |
| 4b | Diametral Pitch | $P = \frac{N}{D}$ | 10b | Pitch Diameter | $D = \frac{Np}{3.1416}$ |
| 4c | Diametral Pitch | $P = \frac{N_P(m_G + 1)}{2C}$ | 11 | Root Diameter | $D_R = D - 2b$ |
| 5 | Gear Ratio | $m_G = \frac{N_G}{N_P}$ | 12 | Whole Depth | $a + b$ |
| | | | 13 | Working Depth | $a_G + a_P$ |

Notation

| | |
|---|---|
| ϕ = Pressure Angle a = Addendum = $1/P$ a_G = Addendum of Gear a_P = Addendum of Pinion b = Dedendum c = Clearance C = Center Distance D = Pitch Diameter D_G = Pitch Diameter of Gear D_P = Pitch Diameter of Pinion D_B = Base Circle Diameter | D_O = Outside Diameter D_R = Root Diameter F = Face Width h_k = Working Depth of Tooth h_t = Whole Depth of Tooth m_G = Gear Ratio N = Number of Teeth N_G = Number of Teeth in Gear N_P = Number of Teeth in Pinion p = Circular Pitch P = Diametral Pitch |
|---|---|

**Table 2. Circular Pitch in Gears—
Pitch Diameters, Outside Diameters, and Root Diameters**

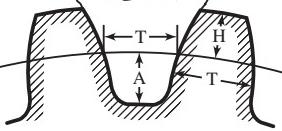
For any particular circular pitch and number of teeth, use the table as shown in the example to find the pitch diameter, outside diameter, and root diameter. *Example:* Pitch diameter for 57 teeth of 6-inch circular pitch = 10× pitch diameter given under factor for 5 teeth plus pitch diameter given under factor for 7 teeth. $(10 \times 9.5493) + 13.3690 = 108.862$ inches.

Outside diameter of gear equals pitch diameter plus outside diameter factor from next-to-last column in table = $108.862 + 3.8197 = 112.682$ inches.

Root diameter of gear equals pitch diameter minus root diameter factor from last column in table = $108.862 - 4.4194 = 104.443$ inches.

| Circular Pitch in Inches | Factor for Number of Teeth | | | | | | | | | Outside Dia. Factor | Root Diameter Factor |
|--|----------------------------|--------|--------|--------|--------|---------|---------|---------|---------|------------------------|----------------------------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | |
| Pitch Diameter Corresponding to Factor for Number of Teeth | | | | | | | | | | | |
| 6 | 1.9099 | 3.8197 | 5.7296 | 7.6394 | 9.5493 | 11.4591 | 13.3690 | 15.2788 | 17.1887 | 3.8197 | 4.4194 |
| 5½ | 1.7507 | 3.5014 | 5.2521 | 7.0028 | 8.7535 | 10.5042 | 12.2549 | 14.0056 | 15.7563 | 3.5014 | 4.0511 |
| 5 | 1.5915 | 3.1831 | 4.7746 | 6.3662 | 7.9577 | 9.5493 | 11.1408 | 12.7324 | 14.3239 | 3.1831 | 3.6828 |
| 4½ | 1.4324 | 2.8648 | 4.2972 | 5.7296 | 7.1620 | 8.5943 | 10.0267 | 11.4591 | 12.8915 | 2.8648 | 3.3146 |
| 4 | 1.2732 | 2.5465 | 3.8197 | 5.0929 | 6.3662 | 7.6394 | 8.9127 | 10.1859 | 11.4591 | 2.5465 | 2.9463 |
| 3½ | 1.1141 | 2.2282 | 3.3422 | 4.4563 | 5.5704 | 6.6845 | 7.7986 | 8.9127 | 10.0267 | 2.2282 | 2.5780 |
| 3 | 0.9549 | 1.9099 | 2.8648 | 3.8197 | 4.7746 | 5.7296 | 6.6845 | 7.6394 | 8.5943 | 1.9099 | 2.2097 |
| 2½ | 0.7958 | 1.5915 | 2.3873 | 3.1831 | 3.9789 | 4.7746 | 5.5704 | 6.3662 | 7.1620 | 1.5915 | 1.8414 |
| 2 | 0.6366 | 1.2732 | 1.9099 | 2.5465 | 3.1831 | 3.8197 | 4.4563 | 5.0929 | 5.7296 | 1.2732 | 1.4731 |
| 1¾ | 0.5968 | 1.1141 | 1.7905 | 2.3873 | 2.9841 | 3.5810 | 4.1778 | 4.7746 | 5.3715 | 1.1141 | 1.3811 |
| 1½ | 0.5570 | 1.1141 | 1.6711 | 2.2282 | 2.7852 | 3.3422 | 3.8993 | 4.4563 | 5.0134 | 1.1141 | 1.2890 |
| 1⅜ | 0.5173 | 1.0345 | 1.5518 | 2.0690 | 2.5863 | 3.1035 | 3.6208 | 4.1380 | 4.6553 | 1.0345 | 1.1969 |
| 1½ | 0.4775 | 0.9549 | 1.4324 | 1.9099 | 2.3873 | 2.8648 | 3.3422 | 3.8197 | 4.2972 | 0.9549 | 1.1049 |
| 1¼ | 0.4576 | 0.9151 | 1.3727 | 1.8303 | 2.2878 | 2.7454 | 3.2030 | 3.6606 | 4.1181 | 0.9151 | 1.0588 |
| 1⅓ | 0.4377 | 0.8754 | 1.3130 | 1.7507 | 2.1884 | 2.6261 | 3.0637 | 3.5014 | 3.9391 | 0.8754 | 1.0128 |
| 1⅛ | 0.4178 | 0.8356 | 1.2533 | 1.6711 | 2.0889 | 2.5067 | 2.9245 | 3.3422 | 3.7600 | 0.8356 | 0.9667 |
| 1¼ | 0.3979 | 0.7958 | 1.1937 | 1.5915 | 1.9894 | 2.3873 | 2.7852 | 3.1831 | 3.5810 | 0.7958 | 0.9207 |
| 1⅓ | 0.3780 | 0.7560 | 1.1340 | 1.5120 | 1.8900 | 2.2680 | 2.6459 | 3.0239 | 3.4019 | 0.7560 | 0.8747 |
| 1⅙ | 0.3581 | 0.7162 | 1.0743 | 1.4324 | 1.7905 | 2.1486 | 2.5067 | 2.8648 | 3.2229 | 0.7162 | 0.8286 |
| 1⅛ | 0.3382 | 0.6764 | 1.0146 | 1.3528 | 1.6910 | 2.0292 | 2.3674 | 2.7056 | 3.0438 | 0.6764 | 0.7826 |
| 1 | 0.3183 | 0.6366 | 0.9549 | 1.2732 | 1.5915 | 1.9099 | 2.2282 | 2.5465 | 2.8648 | 0.6366 | 0.7366 |
| 1⁹₁₆ | 0.2984 | 0.5968 | 0.8952 | 1.1937 | 1.4921 | 1.7905 | 2.0889 | 2.3873 | 2.6857 | 0.5968 | 0.6905 |
| 7/8 | 0.2785 | 0.5570 | 0.8356 | 1.1141 | 1.3926 | 1.6711 | 1.9496 | 2.2282 | 2.5067 | 0.5570 | 0.6445 |
| 1³₁₆ | 0.2586 | 0.5173 | 0.7759 | 1.0345 | 1.2931 | 1.5518 | 1.8104 | 2.0690 | 2.3276 | 0.5173 | 0.5985 |
| ¾ | 0.2387 | 0.4475 | 0.7162 | 0.9549 | 1.1937 | 1.4324 | 1.6711 | 1.9099 | 2.1486 | 0.4775 | 0.5524 |
| 1¹¹₁₆ | 0.2188 | 0.4377 | 0.6565 | 0.8754 | 1.0942 | 1.3130 | 1.5319 | 1.7507 | 1.9695 | 0.4377 | 0.5064 |
| ²/₃ | 0.2122 | 0.4244 | 0.6366 | 0.8488 | 1.0610 | 1.2732 | 1.4854 | 1.6977 | 1.9099 | 0.4244 | 0.4910 |
| ⁵/₈ | 0.1989 | 0.3979 | 0.5968 | 0.7958 | 0.9947 | 1.1937 | 1.3926 | 1.5915 | 1.7905 | 0.3979 | 0.4604 |
| ⁷/₁₆ | 0.1790 | 0.3581 | 0.5371 | 0.7162 | 0.8952 | 1.0743 | 1.2533 | 1.4324 | 1.6114 | 0.3581 | 0.4143 |
| ½ | 0.1592 | 0.3183 | 0.4775 | 0.6366 | 0.7958 | 0.9549 | 1.1141 | 1.2732 | 1.4324 | 0.3183 | 0.3683 |
| ⁹/₁₆ | 0.1393 | 0.2785 | 0.4178 | 0.5570 | 0.6963 | 0.8356 | 0.9748 | 1.1141 | 1.2533 | 0.2785 | 0.3222 |
| ⁷/₈ | 0.1194 | 0.2387 | 0.3581 | 0.4775 | 0.5968 | 0.7162 | 0.8356 | 0.9549 | 1.0743 | 0.2387 | 0.2762 |
| ⁴/₃ | 0.1061 | 0.2122 | 0.3183 | 0.4244 | 0.5305 | 0.6366 | 0.7427 | 0.8488 | 0.9549 | 0.2122 | 0.2455 |
| ⁹/₁₆ | 0.0995 | 0.1989 | 0.2984 | 0.3979 | 0.4974 | 0.5968 | 0.6963 | 0.7958 | 0.8952 | 0.1989 | 0.2302 |
| ⁵/₄ | 0.0796 | 0.1592 | 0.2387 | 0.3183 | 0.3979 | 0.4775 | 0.5570 | 0.6366 | 0.7162 | 0.1592 | 0.1841 |
| ⁹/₁₆ | 0.0597 | 0.1194 | 0.1790 | 0.2387 | 0.2984 | 0.3581 | 0.4178 | 0.4775 | 0.5371 | 0.1194 | 0.1381 |
| ⁷/₈ | 0.0398 | 0.0796 | 0.1194 | 0.1592 | 0.1989 | 0.2387 | 0.2785 | 0.3183 | 0.3581 | 0.0796 | 0.0921 |
| ⁹/₁₆ | 0.0199 | 0.0398 | 0.0597 | 0.0796 | 0.0995 | 0.1194 | 0.1393 | 0.1592 | 0.1790 | 0.0398 | 0.0460 |

Table 3. Chordal Thicknesses and Chordal Addenda of Milled, Full-depth Gear Teeth and of Gear Milling Cutters



The diagram illustrates a cross-section of a gear tooth. It shows the top surface with a horizontal dimension labeled 'T' (chordal thickness). Below the top surface is a horizontal line labeled 'H' (chordal addendum). A vertical dimension labeled 'A' (chordal addendum of cutter) is shown between the top surface and the bottom of the tooth profile.

T = chordal thickness of gear tooth and cutter tooth at pitch line;
H = chordal addendum for full-depth gear tooth;
A = chordal addendum of cutter = $(2.157 \div \text{diametral pitch}) - H = (0.6866 \times \text{circular pitch}) - H$.

| Diametral Pitch | Dimension | Number of Gear Cutter, and Corresponding Number of Teeth | | | | | | | |
|-----------------|-----------|--|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | | No. 1 135 Teeth | No. 2 55 Teeth | No. 3 35 Teeth | No. 4 26 Teeth | No. 5 21 Teeth | No. 6 17 Teeth | No. 7 14 Teeth | No. 8 12 Teeth |
| 1 | T | 1.5707 | 1.5706 | 1.5702 | 1.5698 | 1.5694 | 1.5686 | 1.5675 | 1.5663 |
| | H | 1.0047 | 1.0112 | 1.0176 | 1.0237 | 1.0294 | 1.0362 | 1.0440 | 1.0514 |
| $1\frac{1}{2}$ | T | 1.0471 | 1.0470 | 1.0468 | 1.0465 | 1.0462 | 1.0457 | 1.0450 | 1.0442 |
| | H | 0.6698 | 0.6741 | 0.6784 | 0.6824 | 0.6862 | 0.6908 | 0.6960 | 0.7009 |
| 2 | T | 0.7853 | 0.7853 | 0.7851 | 0.7849 | 0.7847 | 0.7843 | 0.7837 | 0.7831 |
| | H | 0.5023 | 0.5056 | 0.5088 | 0.5118 | 0.5147 | 0.5181 | 0.5220 | 0.5257 |
| $2\frac{1}{2}$ | T | 0.6283 | 0.6282 | 0.6281 | 0.6279 | 0.6277 | 0.6274 | 0.6270 | 0.6265 |
| | H | 0.4018 | 0.4044 | 0.4070 | 0.4094 | 0.4117 | 0.4144 | 0.4176 | 0.4205 |
| 3 | T | 0.5235 | 0.5235 | 0.5234 | 0.5232 | 0.5231 | 0.5228 | 0.5225 | 0.5221 |
| | H | 0.3349 | 0.3370 | 0.3392 | 0.3412 | 0.3431 | 0.3454 | 0.3480 | 0.3504 |
| $3\frac{1}{2}$ | T | 0.4487 | 0.4487 | 0.4486 | 0.4485 | 0.4484 | 0.4481 | 0.4478 | 0.4475 |
| | H | 0.2870 | 0.2889 | 0.2907 | 0.2919 | 0.2935 | 0.2954 | 0.2977 | 0.3004 |
| 4 | T | 0.3926 | 0.3926 | 0.3926 | 0.3924 | 0.3923 | 0.3921 | 0.3919 | 0.3915 |
| | H | 0.2511 | 0.2528 | 0.2544 | 0.2559 | 0.2573 | 0.2590 | 0.2610 | 0.2628 |
| 5 | T | 0.3141 | 0.3141 | 0.3140 | 0.3139 | 0.3138 | 0.3137 | 0.3135 | 0.3132 |
| | H | 0.2009 | 0.2022 | 0.2035 | 0.2047 | 0.2058 | 0.2072 | 0.2088 | 0.2102 |
| 6 | T | 0.2618 | 0.2617 | 0.2617 | 0.2616 | 0.2615 | 0.2614 | 0.2612 | 0.2610 |
| | H | 0.1674 | 0.1685 | 0.1696 | 0.1706 | 0.1715 | 0.1727 | 0.1740 | 0.1752 |
| 7 | T | 0.2244 | 0.2243 | 0.2243 | 0.2242 | 0.2242 | 0.2240 | 0.2239 | 0.2237 |
| | H | 0.1435 | 0.1444 | 0.1453 | 0.1462 | 0.1470 | 0.1480 | 0.1491 | 0.1502 |
| 8 | T | 0.1963 | 0.1963 | 0.1962 | 0.1962 | 0.1961 | 0.1960 | 0.1959 | 0.1958 |
| | H | 0.1255 | 0.1264 | 0.1272 | 0.1279 | 0.1286 | 0.1295 | 0.1305 | 0.1314 |
| 9 | T | 0.1745 | 0.1745 | 0.1744 | 0.1744 | 0.1743 | 0.1743 | 0.1741 | 0.1740 |
| | H | 0.1116 | 0.1123 | 0.1130 | 0.1137 | 0.1143 | 0.1151 | 0.1160 | 0.1168 |
| 10 | T | 0.1570 | 0.1570 | 0.1570 | 0.1569 | 0.1569 | 0.1568 | 0.1567 | 0.1566 |
| | H | 0.1004 | 0.1011 | 0.1017 | 0.1023 | 0.1029 | 0.1036 | 0.1044 | 0.1051 |
| 11 | T | 0.1428 | 0.1428 | 0.1427 | 0.1427 | 0.1426 | 0.1426 | 0.1425 | 0.1424 |
| | H | 0.0913 | 0.0919 | 0.0925 | 0.0930 | 0.0935 | 0.0942 | 0.0949 | 0.0955 |
| 12 | T | 0.1309 | 0.1309 | 0.1308 | 0.1308 | 0.1308 | 0.1307 | 0.1306 | 0.1305 |
| | H | 0.0837 | 0.0842 | 0.0848 | 0.0853 | 0.0857 | 0.0863 | 0.0870 | 0.0876 |
| 14 | T | 0.1122 | 0.1122 | 0.1121 | 0.1121 | 0.1121 | 0.1120 | 0.1119 | 0.1118 |
| | H | 0.0717 | 0.0722 | 0.0726 | 0.0731 | 0.0735 | 0.0740 | 0.0745 | 0.0751 |
| 16 | T | 0.0981 | 0.0981 | 0.0981 | 0.0981 | 0.0980 | 0.0980 | 0.0979 | 0.0979 |
| | H | 0.0628 | 0.0632 | 0.0636 | 0.0639 | 0.0643 | 0.0647 | 0.0652 | 0.0657 |
| 18 | T | 0.0872 | 0.0872 | 0.0872 | 0.0872 | 0.0872 | 0.0871 | 0.0870 | 0.0870 |
| | H | 0.0558 | 0.0561 | 0.0565 | 0.0568 | 0.0571 | 0.0575 | 0.0580 | 0.0584 |
| 20 | T | 0.0785 | 0.0785 | 0.0785 | 0.0785 | 0.0784 | 0.0784 | 0.0783 | 0.0783 |
| | H | 0.0502 | 0.0505 | 0.0508 | 0.0511 | 0.0514 | 0.0518 | 0.0522 | 0.0525 |

Table 4. Chordal Thicknesses and Chordal Addenda of Milled, Full-depth Gear Teeth and of Gear Milling Cutters

| Circular Pitch | Dimension | Number of Gear Cutter, and Corresponding Number of Teeth | | | | | | | |
|-----------------|-----------|--|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | | No. 1 135 Teeth | No. 2 55 Teeth | No. 3 35 Teeth | No. 4 26 Teeth | No. 5 21 Teeth | No. 6 17 Teeth | No. 7 14 Teeth | No. 8 12 Teeth |
| $\frac{1}{4}$ | T | 0.1250 | 0.1250 | 0.1249 | 0.1249 | 0.1249 | 0.1248 | 0.1247 | 0.1246 |
| | H | 0.0799 | 0.0804 | 0.0809 | 0.0814 | 0.0819 | 0.0824 | 0.0830 | 0.0836 |
| $\frac{5}{16}$ | T | 0.1562 | 0.1562 | 0.1562 | 0.1561 | 0.1561 | 0.1560 | 0.1559 | 0.1558 |
| | H | 0.0999 | 0.1006 | 0.1012 | 0.1018 | 0.1023 | 0.1030 | 0.1038 | 0.1045 |
| $\frac{3}{8}$ | T | 0.1875 | 0.1875 | 0.1874 | 0.1873 | 0.1873 | 0.1872 | 0.1871 | 0.1870 |
| | H | 0.1199 | 0.1207 | 0.1214 | 0.1221 | 0.1228 | 0.1236 | 0.1245 | 0.1254 |
| $\frac{7}{16}$ | T | 0.2187 | 0.2187 | 0.2186 | 0.2186 | 0.2185 | 0.2184 | 0.2183 | 0.2181 |
| | H | 0.1399 | 0.1408 | 0.1416 | 0.1425 | 0.1433 | 0.1443 | 0.1453 | 0.1464 |
| $\frac{1}{2}$ | T | 0.2500 | 0.2500 | 0.2499 | 0.2498 | 0.2498 | 0.2496 | 0.2495 | 0.2493 |
| | H | 0.1599 | 0.1609 | 0.1619 | 0.1629 | 0.1638 | 0.1649 | 0.1661 | 0.1673 |
| $\frac{9}{16}$ | T | 0.2812 | 0.2812 | 0.2811 | 0.2810 | 0.2810 | 0.2808 | 0.2806 | 0.2804 |
| | H | 0.1799 | 0.1810 | 0.1821 | 0.1832 | 0.1842 | 0.1855 | 0.1868 | 0.1882 |
| $\frac{5}{8}$ | T | 0.3125 | 0.3125 | 0.3123 | 0.3123 | 0.3122 | 0.3120 | 0.3118 | 0.3116 |
| | H | 0.1998 | 0.2012 | 0.2023 | 0.2036 | 0.2047 | 0.2061 | 0.2076 | 0.2091 |
| $\frac{11}{16}$ | T | 0.3437 | 0.3437 | 0.3436 | 0.3435 | 0.3434 | 0.3432 | 0.3430 | 0.3427 |
| | H | 0.2198 | 0.2213 | 0.2226 | 0.2239 | 0.2252 | 0.2267 | 0.2283 | 0.2300 |
| $\frac{3}{4}$ | T | 0.3750 | 0.3750 | 0.3748 | 0.3747 | 0.3747 | 0.3744 | 0.3742 | 0.3740 |
| | H | 0.2398 | 0.2414 | 0.2428 | 0.2443 | 0.2457 | 0.2473 | 0.2491 | 0.2509 |
| $\frac{13}{16}$ | T | 0.4062 | 0.4062 | 0.4060 | 0.4059 | 0.4059 | 0.4056 | 0.4054 | 0.4050 |
| | H | 0.2598 | 0.2615 | 0.2631 | 0.2647 | 0.2661 | 0.2679 | 0.2699 | 0.2718 |
| $\frac{7}{8}$ | T | 0.4375 | 0.4375 | 0.4373 | 0.4372 | 0.4371 | 0.4368 | 0.4366 | 0.4362 |
| | H | 0.2798 | 0.2816 | 0.2833 | 0.2850 | 0.2866 | 0.2885 | 0.2906 | 0.2927 |
| $\frac{15}{16}$ | T | 0.4687 | 0.4687 | 0.4685 | 0.4684 | 0.4683 | 0.4680 | 0.4678 | 0.4674 |
| | H | 0.2998 | 0.3018 | 0.3035 | 0.3054 | 0.3071 | 0.3092 | 0.3114 | 0.3137 |
| 1 | T | 0.5000 | 0.5000 | 0.4998 | 0.4997 | 0.4996 | 0.4993 | 0.4990 | 0.4986 |
| | H | 0.3198 | 0.3219 | 0.3238 | 0.3258 | 0.3276 | 0.3298 | 0.3322 | 0.3346 |
| $1\frac{1}{8}$ | T | 0.5625 | 0.5625 | 0.5623 | 0.5621 | 0.5620 | 0.5617 | 0.5613 | 0.5610 |
| | H | 0.3597 | 0.3621 | 0.3642 | 0.3665 | 0.3685 | 0.3710 | 0.3737 | 0.3764 |
| $1\frac{1}{4}$ | T | 0.6250 | 0.6250 | 0.6247 | 0.6246 | 0.6245 | 0.6241 | 0.6237 | 0.6232 |
| | H | 0.3997 | 0.4023 | 0.4047 | 0.4072 | 0.4095 | 0.4122 | 0.4152 | 0.4182 |
| $1\frac{5}{8}$ | T | 0.6875 | 0.6875 | 0.6872 | 0.6870 | 0.6869 | 0.6865 | 0.6861 | 0.6856 |
| | H | 0.4397 | 0.4426 | 0.4452 | 0.4479 | 0.4504 | 0.4534 | 0.4567 | 0.4600 |
| $1\frac{1}{2}$ | T | 0.7500 | 0.7500 | 0.7497 | 0.7495 | 0.7494 | 0.7489 | 0.7485 | 0.7480 |
| | H | 0.4797 | 0.4828 | 0.4857 | 0.4887 | 0.4914 | 0.4947 | 0.4983 | 0.5019 |
| $1\frac{3}{4}$ | T | 0.8750 | 0.8750 | 0.8746 | 0.8744 | 0.8743 | 0.8737 | 0.8732 | 0.8726 |
| | H | 0.5596 | 0.5633 | 0.5666 | 0.5701 | 0.5733 | 0.5771 | 0.5813 | 0.5855 |
| 2 | T | 1.0000 | 1.0000 | 0.9996 | 0.9994 | 0.9992 | 0.9986 | 0.9980 | 0.9972 |
| | H | 0.6396 | 0.6438 | 0.6476 | 0.6516 | 0.6552 | 0.6596 | 0.6644 | 0.6692 |
| $2\frac{1}{4}$ | T | 1.1250 | 1.1250 | 1.1246 | 1.1242 | 1.1240 | 1.1234 | 1.1226 | 1.1220 |
| | H | 0.7195 | 0.7242 | 0.7285 | 0.7330 | 0.7371 | 0.7420 | 0.7474 | 0.7528 |
| $2\frac{1}{2}$ | T | 1.2500 | 1.2500 | 1.2494 | 1.2492 | 1.2490 | 1.2482 | 1.2474 | 1.2464 |
| | H | 0.7995 | 0.8047 | 0.8095 | 0.8145 | 0.8190 | 0.8245 | 0.8305 | 0.8365 |
| 3 | T | 1.5000 | 1.5000 | 1.4994 | 1.4990 | 1.4990 | 1.4978 | 1.4970 | 1.4960 |
| | H | 0.9594 | 0.9657 | 0.9714 | 0.9774 | 0.9828 | 0.9894 | 0.9966 | 1.0038 |

Table 5. Series of Involute, Finishing Gear Milling Cutters for Each Pitch

| Number of Cutter | Will cut Gears from | Number of Cutter | Will cut Gears from |
|------------------|---------------------|------------------|---------------------|
| 1 | 135 teeth to a rack | 5 | 21 to 25 teeth |
| 2 | 55 to 134 teeth | 6 | 17 to 20 teeth |
| 3 | 35 to 54 teeth | 7 | 14 to 16 teeth |
| 4 | 26 to 34 teeth | 8 | 12 to 13 teeth |

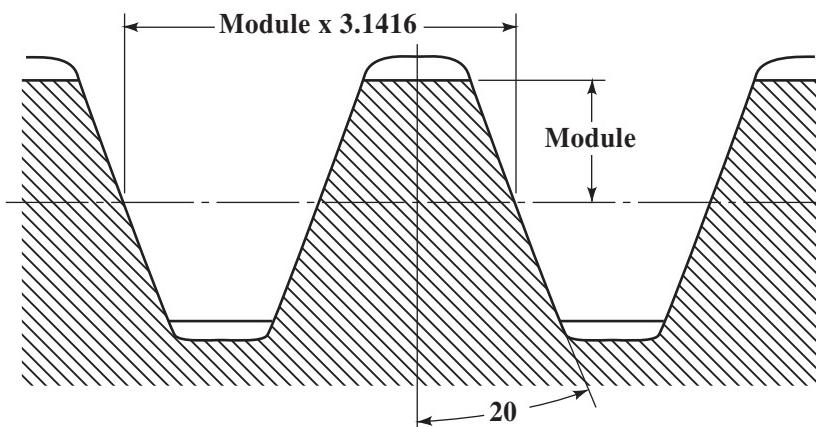
The regular cutters listed above are used ordinarily. The cutters listed below (an intermediate series having half numbers) may be used when greater accuracy of tooth shape is essential in cases where the number of teeth is between the numbers for which the regular cutters are intended.

| Number of Cutter | Will cut Gears from | Number of Cutter | Will cut Gears from |
|------------------|---------------------|------------------|---------------------|
| $1\frac{1}{2}$ | 80 to 134 teeth | $5\frac{1}{2}$ | 19 to 20 teeth |
| $2\frac{1}{2}$ | 42 to 54 teeth | $6\frac{1}{2}$ | 15 to 16 teeth |
| $3\frac{1}{2}$ | 30 to 34 teeth | $7\frac{1}{2}$ | 13 teeth |
| $4\frac{1}{2}$ | 23 to 25 teeth | ... | ... |

Roughing cutters are made with No. 1 form only.

Gear Design Based upon Module System.— The *module* of a gear is equal to the pitch diameter divided by the number of teeth, whereas *diametral pitch* is equal to the number of teeth divided by the pitch diameter. The module system (see accompanying table and diagram) is in general use in countries that have adopted the metric system; hence, the term module is usually understood to mean the pitch diameter *in millimeters* divided by the number of teeth. The module system, however, may also be based on inch measurements and then it is known as the English module to avoid confusion with the metric module. Module is an actual dimension, whereas diametral pitch is only a ratio. Thus, if the pitch diameter of a gear is 50 millimeters and the number of teeth 25, the module is 2, which means that there are 2 millimeters of pitch diameter for each tooth. The table *Tooth Dimensions Based Upon Module System* shows the relation among module, diametral pitch, and circular pitch.

Table 6. German Standard Tooth Form for Spur and Bevel Gears DIN—867



The flanks or sides are straight (involute system) and the pressure angle is 20 degrees. The shape of the root clearance space and the amount of clearance depend upon the method of cutting and special requirements. The amount of clearance may vary from $0.1 \times \text{module}$ to $0.3 \times \text{module}$.

| To Find | Module Known | Circular Pitch Known |
|-------------------------------|--|--|
| Addendum | Equals module | $0.31823 \times \text{Circular pitch}$ |
| Dedendum | $1.157 \times \text{module}^a$ $1.167 \times \text{module}^b$ | $0.3683 \times \text{Circular pitch}^a$ $0.3714 \times \text{Circular pitch}^b$ |
| Working Depth | $2 \times \text{module}$ | $0.6366 \times \text{Circular pitch}$ |
| Total Depth | $2.157 \times \text{module}^a$ $2.167 \times \text{module}^b$ | $0.6866 \times \text{Circular pitch}^a$ $0.6898 \times \text{Circular pitch}^b$ |
| Tooth Thickness on Pitch Line | $1.5708 \times \text{module}$ | $0.5 \times \text{Circular pitch}$ |

^aFormulas for dedendum and total depth, are used when clearance equals $0.157 \times \text{module}$. Formulas marked

^bFormulas for dedendum and total depth, are used when clearance equals one-sixth module. It is common practice among American cutter manufacturers to make the clearance of metric or module cutters equal to $0.157 \times \text{module}$

Table 7. Tooth Dimensions Based Upon Module System

| Module, DIN Standard Series | Equivalent Diametral Pitch | Circular Pitch | | Addendum, Millimeters | Dedendum, Millimeters ^a | Whole Depth, ^a Millimeters | Whole Depth, ^b Millimeters |
|--------------------------------------|----------------------------------|----------------|--------|--------------------------|---------------------------------------|---|---|
| | | Millimeters | Inches | | | | |
| 0.3 | 84.667 | 0.943 | 0.0371 | 0.30 | 0.35 | 0.650 | 0.647 |
| 0.4 | 63.500 | 1.257 | 0.0495 | 0.40 | 0.467 | 0.867 | 0.863 |
| 0.5 | 50.800 | 1.571 | 0.0618 | 0.50 | 0.583 | 1.083 | 1.079 |
| 0.6 | 42.333 | 1.885 | 0.0742 | 0.60 | 0.700 | 1.300 | 1.294 |
| 0.7 | 36.286 | 2.199 | 0.0865 | 0.70 | 0.817 | 1.517 | 1.510 |
| 0.8 | 31.750 | 2.513 | 0.0989 | 0.80 | 0.933 | 1.733 | 1.726 |
| 0.9 | 28.222 | 2.827 | 0.1113 | 0.90 | 1.050 | 1.950 | 1.941 |
| 1 | 25.400 | 3.142 | 0.1237 | 1.00 | 1.167 | 2.167 | 2.157 |
| 1.25 | 20.320 | 3.927 | 0.1546 | 1.25 | 1.458 | 2.708 | 2.697 |
| 1.5 | 16.933 | 4.712 | 0.1855 | 1.50 | 1.750 | 3.250 | 3.236 |
| 1.75 | 14.514 | 5.498 | 0.2164 | 1.75 | 2.042 | 3.792 | 3.774 |
| 2 | 12.700 | 6.283 | 0.2474 | 2.00 | 2.333 | 4.333 | 4.314 |
| 2.25 | 11.289 | 7.069 | 0.2783 | 2.25 | 2.625 | 4.875 | 4.853 |
| 2.5 | 10.160 | 7.854 | 0.3092 | 2.50 | 2.917 | 5.417 | 5.392 |
| 2.75 | 9.236 | 8.639 | 0.3401 | 2.75 | 3.208 | 5.958 | 5.932 |
| 3 | 8.466 | 9.425 | 0.3711 | 3.00 | 3.500 | 6.500 | 6.471 |
| 3.25 | 7.815 | 10.210 | 0.4020 | 3.25 | 3.791 | 7.041 | 7.010 |
| 3.5 | 7.257 | 10.996 | 0.4329 | 3.50 | 4.083 | 7.583 | 7.550 |
| 3.75 | 6.773 | 11.781 | 0.4638 | 3.75 | 4.375 | 8.125 | 8.089 |
| 4 | 6.350 | 12.566 | 0.4947 | 4.00 | 4.666 | 8.666 | 8.628 |
| 4.5 | 5.644 | 14.137 | 0.5566 | 4.50 | 5.25 | 9.750 | 9.707 |
| 5 | 5.080 | 15.708 | 0.6184 | 5.00 | 5.833 | 10.833 | 10.785 |
| 5.5 | 4.618 | 17.279 | 0.6803 | 5.50 | 6.416 | 11.916 | 11.864 |
| 6 | 4.233 | 18.850 | 0.7421 | 6.00 | 7.000 | 13.000 | 12.942 |
| 6.5 | 3.908 | 20.420 | 0.8035 | 6.50 | 7.583 | 14.083 | 14.021 |
| 7 | 3.628 | 21.991 | 0.8658 | 7 | 8.166 | 15.166 | 15.099 |
| 8 | 3.175 | 25.132 | 0.9895 | 8 | 9.333 | 17.333 | 17.256 |
| 9 | 2.822 | 28.274 | 1.1132 | 9 | 10.499 | 19.499 | 19.413 |
| 10 | 2.540 | 31.416 | 1.2368 | 10 | 11.666 | 21.666 | 21.571 |
| 11 | 2.309 | 34.558 | 1.3606 | 11 | 12.833 | 23.833 | 23.728 |
| 12 | 2.117 | 37.699 | 1.4843 | 12 | 14.000 | 26.000 | 25.884 |
| 13 | 1.954 | 40.841 | 1.6079 | 13 | 15.166 | 28.166 | 28.041 |
| 14 | 1.814 | 43.982 | 1.7317 | 14 | 16.332 | 30.332 | 30.198 |
| 15 | 1.693 | 47.124 | 1.8541 | 15 | 17.499 | 32.499 | 32.355 |
| 16 | 1.587 | 50.266 | 1.9790 | 16 | 18.666 | 34.666 | 34.512 |
| 18 | 1.411 | 56.549 | 2.2263 | 18 | 21.000 | 39.000 | 38.826 |
| 20 | 1.270 | 62.832 | 2.4737 | 20 | 23.332 | 43.332 | 43.142 |
| 22 | 1.155 | 69.115 | 2.7210 | 22 | 25.665 | 47.665 | 47.454 |
| 24 | 1.058 | 75.398 | 2.9685 | 24 | 28.000 | 52.000 | 51.768 |
| 27 | 0.941 | 84.823 | 3.339 | 27 | 31.498 | 58.498 | 58.239 |
| 30 | 0.847 | 94.248 | 3.711 | 30 | 35.000 | 65.000 | 64.713 |
| 33 | 0.770 | 103.673 | 4.082 | 33 | 38.498 | 71.498 | 71.181 |
| 36 | 0.706 | 113.097 | 4.453 | 36 | 41.998 | 77.998 | 77.652 |
| 39 | 0.651 | 122.522 | 4.824 | 39 | 45.497 | 84.497 | 84.123 |
| 42 | 0.605 | 131.947 | 5.195 | 42 | 48.997 | 90.997 | 90.594 |
| 45 | 0.564 | 141.372 | 5.566 | 45 | 52.497 | 97.497 | 97.065 |
| 50 | 0.508 | 157.080 | 6.184 | 50 | 58.330 | 108.330 | 107.855 |
| 55 | 0.462 | 172.788 | 6.803 | 55 | 64.163 | 119.163 | 118.635 |
| 60 | 0.423 | 188.496 | 7.421 | 60 | 69.996 | 129.996 | 129.426 |
| 65 | 0.391 | 204.204 | 8.040 | 65 | 75.829 | 140.829 | 140.205 |
| 70 | 0.363 | 219.911 | 8.658 | 70 | 81.662 | 151.662 | 150.997 |
| 75 | 0.339 | 235.619 | 9.276 | 75 | 87.495 | 162.495 | 161.775 |

^aDedendum and total depth when clearance = $0.1666 \times \text{module}$, or one-sixth module.^bTotal depth equivalent to American standard full-depth teeth. (Clearance = $0.157 \times \text{module}$.)

Table 8. Rules for Module System of Gearing

| To Find | Rule |
|---|---|
| Metric Module | <p><i>Rule 1:</i> To find the metric module, divide the pitch diameter in millimeters by the number of teeth.</p> <p><i>Example 1:</i> The pitch diameter of a gear is 200 millimeters and the number of teeth, 40; then</p> $\text{Module} = \frac{200}{40} = 5$ <p><i>Rule 2:</i> Multiply circular pitch in millimeters by 0.3183.</p> <p><i>Example 2:</i> (Same as Example 1. Circular pitch of this gear equals 15.708 millimeters.)</p> $\text{Module} = 15.708 \times 0.3183 = 5$ <p><i>Rule 3:</i> Divide outside diameter in millimeters by the number of teeth plus 2.</p> |
| English Module | <p><i>Note:</i> The module system is usually applied when gear dimensions are expressed in millimeters, but module may also be based on inch measurements.</p> <p><i>Rule:</i> To find the English module, divide pitch diameter in inches by the number of teeth.</p> <p><i>Example:</i> A gear has 48 teeth and a pitch diameter of 12 inches.</p> $\text{Module} = \frac{12}{48} = \frac{1}{4} \text{ module or } 4 \text{ diametral pitch}$ |
| Metric Module Equivalent to Diametral Pitch | <p><i>Rule:</i> To find the metric module equivalent to a given diametral pitch, divide 25.4 by the diametral pitch.</p> <p><i>Example:</i> Determine metric module equivalent to 10 diametral pitch.</p> $\text{Equivalent module} = \frac{25.4}{10} = 2.54$ <p><i>Note:</i> The nearest standard module is 2.5.</p> |
| Diametral Pitch Equivalent to Metric Module | <p><i>Rule:</i> To find the diametral pitch equivalent to a given module, divide 25.4 by the module. (25.4 = number of millimeters per inch.)</p> <p><i>Example:</i> The module is 12; determine equivalent diametral pitch.</p> $\text{Equivalent diametral pitch} = \frac{25.4}{12} = 2.117$ <p><i>Note:</i> A diametral pitch of 2 is the nearest <i>standard</i> equivalent.</p> |
| Pitch Diameter | <p><i>Rule:</i> Multiply number of teeth by module.</p> <p><i>Example:</i> The metric module is 8 and the gear has 40 teeth; then</p> $D = 40 \times 8 = 320 \text{ millimeters} = 12.598 \text{ inches}$ |
| Outside Diameter | <p><i>Rule:</i> Add 2 to the number of teeth and multiply sum by the module.</p> <p><i>Example:</i> A gear has 40 teeth and module is 6. Find outside or blank diameter.</p> $\text{Outside diameter} = (40 + 2) \times 6 = 252 \text{ millimeters}$ |

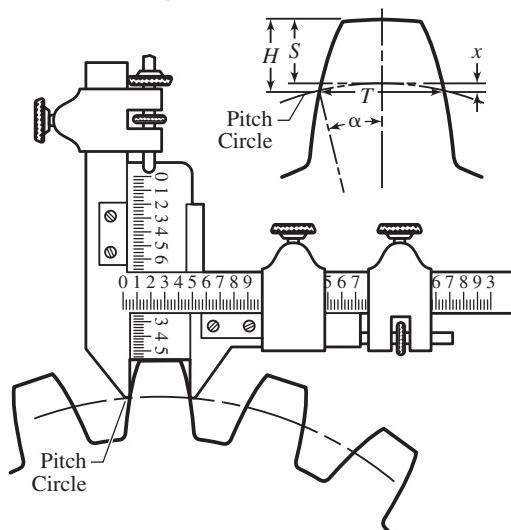
For tooth dimensions, see table *Tooth Dimensions Based Upon Module System*; also formulas in *German Standard Tooth Form for Spur and Bevel Gears DIN—867*.

Table 9. Equivalent Diametral Pitches, Circular Pitches, and Metric Modules
 Commonly Used Pitches and Modules in Bold Type

| Diametral Pitch | Circular Pitch, Inches | Module Millimeters | Diametral Pitch | Circular Pitch, Inches | Module Millimeters | Diametral Pitch | Circular Pitch, Inches | Module Millimeters |
|----------------------------------|----------------------------------|--------------------|----------------------------------|----------------------------------|----------------------------------|-----------------|------------------------|--------------------|
| $\frac{1}{2}$ | 6.2832 | 50.8000 | 2.2848 | $1\frac{3}{8}$ | 11.1170 | 10.0531 | $\frac{5}{16}$ | 2.5266 |
| 0.5080 | 6.1842 | 50 | 2.3091 | 1.3605 | 11 | 10.1600 | 0.3092 | $2\frac{1}{2}$ |
| 0.5236 | 6 | 48.5104 | $2\frac{1}{2}$ | 1.2566 | 10.1600 | 11 | 0.2856 | 2.3091 |
| 0.5644 | 5.5658 | 45 | 2.5133 | $1\frac{1}{4}$ | 10.1063 | 12 | 0.2618 | 2.1167 |
| 0.5712 | $5\frac{1}{2}$ | 44.4679 | 2.5400 | 1.2368 | 10 | 12.5664 | $\frac{1}{4}$ | 2.0213 |
| 0.6283 | 5 | 40.4253 | $2\frac{3}{4}$ | 1.1424 | 9.2364 | 12.7000 | 0.2474 | 2 |
| 0.6350 | 4.9474 | 40 | 2.7925 | $1\frac{1}{8}$ | 9.0957 | 13 | 0.2417 | 1.9538 |
| 0.6981 | $4\frac{1}{2}$ | 36.3828 | 2.8222 | 1.1132 | 9 | 14 | 0.2244 | 1.8143 |
| 0.7257 | 4.3290 | 35 | 3 | 1.0472 | 8.4667 | 15 | 0.2094 | 1.6933 |
| $\frac{3}{4}$ | 4.1888 | 33.8667 | 3.1416 | 1 | 8.0851 | 16 | 0.1963 | 1.5875 |
| 0.7854 | 4 | 32.3403 | 3.1750 | 0.9895 | 8 | 16.7552 | $\frac{3}{16}$ | 1.5160 |
| 0.8378 | $3\frac{3}{4}$ | 30.3190 | 3.3510 | $1\frac{5}{16}$ | 7.5797 | 16.9333 | 0.1855 | $1\frac{1}{2}$ |
| 0.8467 | 3.7105 | 30 | $3\frac{1}{2}$ | 0.8976 | 7.2571 | 17 | 0.1848 | 1.4941 |
| 0.8976 | $3\frac{1}{2}$ | 28.2977 | 3.5904 | $\frac{7}{8}$ | 7.0744 | 18 | 0.1745 | 1.4111 |
| 0.9666 | $3\frac{1}{4}$ | 26.2765 | 3.6286 | 0.8658 | 7 | 19 | 0.1653 | 1.3368 |
| 1 | 3.1416 | 25.4000 | 3.8666 | $1\frac{3}{16}$ | 6.5691 | 20 | 0.1571 | 1.2700 |
| 1.0160 | 3.0921 | 25 | 3.9078 | 0.8040 | $6\frac{1}{2}$ | 22 | 0.1428 | 1.1545 |
| 1.0472 | 3 | 24.2552 | 4 | 0.7854 | 6.3500 | 24 | 0.1309 | 1.0583 |
| 1.1424 | $2\frac{3}{4}$ | 22.2339 | 4.1888 | $\frac{3}{4}$ | 6.0638 | 25 | 0.1257 | 1.0160 |
| $1\frac{1}{4}$ | 2.5133 | 20.3200 | 4.2333 | 0.7421 | 6 | 25.1328 | $\frac{1}{8}$ | 1.0106 |
| 1.2566 | $2\frac{1}{2}$ | 20.2127 | 4.5696 | $1\frac{1}{16}$ | 5.5585 | 25.4000 | 0.1237 | 1 |
| 1.2700 | 2.4737 | 20 | 4.6182 | 0.6803 | $5\frac{1}{2}$ | 26 | 0.1208 | 0.9769 |
| 1.3963 | $2\frac{1}{4}$ | 18.1914 | 5 | 0.6283 | 5.0800 | 28 | 0.1122 | 0.9071 |
| 1.4111 | 2.2263 | 18 | 5.0265 | $\frac{5}{8}$ | 5.0532 | 30 | 0.1047 | 0.8467 |
| $1\frac{1}{2}$ | 2.0944 | 16.9333 | 5.0800 | 0.6184 | 5 | 32 | 0.0982 | 0.7937 |
| 1.5708 | 2 | 16.1701 | 5.5851 | $\frac{9}{16}$ | 4.5478 | 34 | 0.0924 | 0.7470 |
| 1.5875 | 1.9790 | 16 | 5.6443 | 0.5566 | $4\frac{1}{2}$ | 36 | 0.0873 | 0.7056 |
| 1.6755 | $1\frac{7}{8}$ | 15.1595 | 6 | 0.5236 | 4.2333 | 38 | 0.0827 | 0.6684 |
| 1.6933 | 1.8553 | 15 | 6.2832 | $\frac{1}{2}$ | 4.0425 | 40 | 0.0785 | 0.6350 |
| $1\frac{3}{4}$ | 1.7952 | 14.5143 | 6.3500 | 0.4947 | 4 | 42 | 0.0748 | 0.6048 |
| 1.7952 | $1\frac{3}{4}$ | 14.1489 | 7 | 0.4488 | 3.6286 | 44 | 0.0714 | 0.5773 |
| 1.8143 | 1.7316 | 14 | 7.1808 | $\frac{7}{16}$ | 3.5372 | 46 | 0.0683 | 0.5522 |
| 1.9333 | $1\frac{5}{8}$ | 13.1382 | 7.2571 | 0.4329 | $3\frac{1}{2}$ | 48 | 0.0654 | 0.5292 |
| 1.9538 | 1.6079 | 13 | 8 | 0.3927 | 3.1750 | 50 | 0.0628 | 0.5080 |
| 2 | 1.5708 | 12.7000 | 8.3776 | $\frac{3}{8}$ | 3.0319 | 50.2656 | $\frac{5}{16}$ | 0.5053 |
| 2.0944 | $1\frac{1}{2}$ | 12.1276 | 8.4667 | 0.3711 | 3 | 50.8000 | 0.0618 | $\frac{1}{2}$ |
| 2.1167 | 1.4842 | 12 | 9 | 0.3491 | 2.8222 | 56 | 0.0561 | 0.4536 |
| $2\frac{1}{4}$ | 1.3963 | 11.2889 | 10 | 0.3142 | 2.5400 | 60 | 0.0524 | 0.4233 |

The module of a gear is the pitch diameter divided by the number of teeth. The module may be expressed in any units; but when no units are stated, it is understood to be in millimeters. The metric module, therefore, equals the pitch diameter in millimeters divided by the number of teeth. To find the metric module equivalent to a given diametral pitch, divide 25.4 by the diametral pitch. To find the diametral pitch equivalent to a given module, divide 25.4 by the module. (25.4 = number of millimeters per inch.)

Caliper Measurement of Gear Tooth.—In cutting gear teeth, the general practice is to adjust the cutter or hob until it grazes the outside diameter of the blank; the cutter is then sunk to the total depth of the tooth space plus whatever slight additional amount may be required to provide the necessary play or backlash between the teeth. If the outside diameter of the gear blank is correct, the tooth thickness should also be correct after the cutter has been sunk to the depth required for a given pitch and backlash. However, it is advisable to check the tooth thickness by measuring it, and the vernier gear-tooth caliper (see illustration) is commonly used in measuring the thickness.



Method of setting a gear tooth caliper

The vertical scale of this caliper is set so that when it rests upon the top of the tooth as shown, the lower ends of the caliper jaws will be at the height of the pitch circle; the horizontal scale then shows the chordal thickness of the tooth at this point. If the gear is being cut on a milling machine or with the type of gear-cutting machine employing a formed milling cutter, the tooth thickness is checked by first taking a trial cut for a short distance at one side of the blank; then the gear blank is indexed for the next space and another cut is taken far enough to mill the full outline of the tooth. The tooth thickness is then measured.

Before the gear-tooth caliper can be used, it is necessary to determine both the correct chordal thickness and also chordal addendum (or "corrected addendum" as it is sometimes called). The vertical scale is set to the chordal addendum, thus locating the ends of the jaws at the height of the pitch circle. The rules or formulas to use in determining the chordal thickness and chordal addendum will depend upon the outside diameter of the gear; for example, if the outside diameter of a small pinion is enlarged to avoid undercut and improve the tooth action, this must be taken into account in figuring the chordal thickness and chordal addendum as shown by the accompanying rules. The detail of a gear tooth included with the gear-tooth caliper illustration, represents the chordal thickness T , the addendum S , and the chordal addendum H .

Checking Spur Gear Size by Chordal Measurement Over Two or More Teeth.—

Another method of checking gear sizes, that is generally available, is illustrated by the diagram accompanying Table 10. A vernier caliper is used to measure the distance M over two or more teeth. The diagram illustrates the measurement over two teeth (or with one intervening tooth space), but three or more teeth might be included, depending upon the pitch. The jaws of the caliper are merely held in contact with the sides or profiles of the teeth and perpendicular to the axis of the gear. Measurement M for involute teeth of the correct size is determined as follows

Table 10. Chordal Dimensions over Spur Gear Teeth of 1 Diametral Pitch

Find value of M under pressure angle and opposite number of teeth; divide M by diametral pitch of gear to be measured and then subtract one-half total backlash to obtain a measurement M equivalent to given pitch and backlash. The number of teeth to gage or measure over is shown by the next Table 11

| Number of Gear Teeth | M in Inches for 1 D.P. | Number of Gear Teeth | M in Inches for 1 D.P. | Number of Gear Teeth | M in Inches for 1 D.P. | Number of Gear Teeth | M in Inches for 1 D.P. |
|-----------------------------|--------------------------|----------------------|--------------------------|----------------------|--------------------------|----------------------|--------------------------|
| Pressure Angle, 14½ Degrees | | | | | | | |
| 12 | 4.6267 | 37 | 7.8024 | 62 | 14.0197 | 87 | 20.2370 |
| 13 | 4.6321 | 38 | 10.8493 | 63 | 17.0666 | 88 | 23.2838 |
| 14 | 4.6374 | 39 | 10.8547 | 64 | 17.0720 | 89 | 23.2892 |
| 15 | 4.6428 | 40 | 10.8601 | 65 | 17.0773 | 90 | 23.2946 |
| 16 | 4.6482 | 41 | 10.8654 | 66 | 17.0827 | 91 | 23.2999 |
| 17 | 4.6536 | 42 | 10.8708 | 67 | 17.0881 | 92 | 23.3053 |
| 18 | 4.6589 | 43 | 10.8762 | 68 | 17.0934 | 93 | 23.3107 |
| 19 | 7.7058 | 44 | 10.8815 | 69 | 17.0988 | 94 | 23.3160 |
| 20 | 7.7112 | 45 | 10.8869 | 70 | 17.1042 | 95 | 23.3214 |
| 21 | 7.7166 | 46 | 10.8923 | 71 | 17.1095 | 96 | 23.3268 |
| 22 | 7.7219 | 47 | 10.8976 | 72 | 17.1149 | 97 | 23.3322 |
| 23 | 7.7273 | 48 | 10.9030 | 73 | 17.1203 | 98 | 23.3375 |
| 24 | 7.7326 | 49 | 10.9084 | 74 | 17.1256 | 99 | 23.3429 |
| 25 | 7.7380 | 50 | 10.9137 | 75 | 17.1310 | 100 | 23.3483 |
| 26 | 7.7434 | 51 | 13.9606 | 76 | 20.1779 | 101 | 26.3952 |
| 27 | 7.7488 | 52 | 13.9660 | 77 | 20.1833 | 102 | 26.4005 |
| 28 | 7.7541 | 53 | 13.9714 | 78 | 20.1886 | 103 | 26.4059 |
| 29 | 7.7595 | 54 | 13.9767 | 79 | 20.1940 | 104 | 26.4113 |
| 30 | 7.7649 | 55 | 13.9821 | 80 | 20.1994 | 105 | 26.4166 |
| 31 | 7.7702 | 56 | 13.9875 | 81 | 20.2047 | 106 | 26.4220 |
| 32 | 7.7756 | 57 | 13.9929 | 82 | 20.2101 | 107 | 26.4274 |
| 33 | 7.7810 | 58 | 13.9982 | 83 | 20.2155 | 108 | 26.4327 |
| 34 | 7.7683 | 59 | 14.0036 | 84 | 20.2208 | 109 | 26.4381 |
| 35 | 7.7917 | 60 | 14.0090 | 85 | 20.2262 | 110 | 26.4435 |
| 36 | 7.7971 | 61 | 14.0143 | 86 | 20.2316 | ... | ... |
| Pressure Angle, 20 Degrees | | | | | | | |
| 12 | 4.5963 | 30 | 10.7526 | 48 | 16.9090 | 66 | 23.0653 |
| 13 | 4.6103 | 31 | 10.7666 | 49 | 16.9230 | 67 | 23.0793 |
| 14 | 4.6243 | 32 | 10.7806 | 50 | 16.9370 | 68 | 23.0933 |
| 15 | 4.6383 | 33 | 10.7946 | 51 | 16.9510 | 69 | 23.1073 |
| 16 | 4.6523 | 34 | 10.8086 | 52 | 16.9650 | 70 | 23.1214 |
| 17 | 4.6663 | 35 | 10.8226 | 53 | 16.9790 | 71 | 23.1354 |
| 18 | 4.6803 | 36 | 10.8366 | 54 | 16.9930 | 72 | 23.1494 |
| 19 | 7.6464 | 37 | 13.8028 | 55 | 19.9591 | 73 | 26.1155 |
| 20 | 7.6604 | 38 | 13.8168 | 56 | 19.9731 | 74 | 26.1295 |
| 21 | 7.6744 | 39 | 13.8307 | 57 | 19.9872 | 75 | 26.1435 |
| 22 | 7.6884 | 40 | 13.8447 | 58 | 20.0012 | 76 | 26.1575 |
| 23 | 7.7024 | 41 | 13.8587 | 59 | 20.0152 | 77 | 26.1715 |
| 24 | 7.7165 | 42 | 13.8727 | 60 | 20.0292 | 78 | 26.1855 |
| 25 | 7.7305 | 43 | 13.8867 | 61 | 20.0432 | 79 | 26.1995 |
| 26 | 7.7445 | 44 | 13.9007 | 62 | 20.0572 | 80 | 26.2135 |
| 27 | 7.7585 | 45 | 13.9147 | 63 | 20.0712 | 81 | 26.2275 |
| 28 | 10.7246 | 46 | 16.8810 | 64 | 23.0373 | ... | ... |
| 29 | 10.7386 | 47 | 16.8950 | 65 | 23.0513 | ... | ... |

Table for Determining the Chordal Dimension: The Table above gives the chordal dimensions for one diametral pitch when measuring over the number of teeth indicated in the next Table. To obtain any chordal dimension, it is simply necessary to divide chord M in the table (opposite the given number of teeth) by the diametral pitch of the gear to be measured and then subtract from the quotient one-half the total backlash between the mating pair of gears. Where a small pinion is used with a large gear and all of the backlash is to be obtained by reducing the gear teeth, the total amount of backlash is subtracted from the chordal dimension of the gear and nothing from the chordal dimension of the pinion. The application of the tables will be illustrated by an example.

Table 11. Number of Teeth Included in Chordal Measurement

| Tooth Range for $14\frac{1}{2}$ Pressure Angle | Tooth Range for 20° Pressure Angle | Number of Teeth to Gage Over | Tooth Range for $14\frac{1}{2}$ Pressure Angle | Tooth Range for 20° Pressure Angle | Number of Teeth to Gage Over |
|--|---|------------------------------|--|---|------------------------------|
| 12 to 18 | 12 to 18 | 2 | 63 to 75 | 46 to 54 | 6 |
| 19 to 37 | 19 to 27 | 3 | 76 to 87 | 55 to 63 | 7 |
| 38 to 50 | 28 to 36 | 4 | 88 to 100 | 64 to 72 | 8 |
| 51 to 62 | 37 to 45 | 5 | 101 to 110 | 73 to 81 | 9 |

This table shows the number of teeth to be included between the jaws of the vernier caliper in measuring dimension M as explained in connection with Table 10.

Example: Determine the chordal dimension for checking the size of a gear having 30 teeth of 5 diametral pitch and a pressure angle of 20 degrees. A total backlash of 0.008 inch is to be obtained by reducing equally the teeth of both mating gears.

Table 10 shows that the chordal distance for 30 teeth of one diametral pitch and a pressure angle of 20 degrees is 10.7526 inches; one-half of the backlash equals 0.004 inch; hence,

$$\text{Chordal dimension} = \frac{10.7526}{5} - 0.004 = 2.1465 \text{ inches}$$

Table 11 shows that this is the chordal dimension when the vernier caliper spans four teeth, this being the number of teeth to gage over whenever gears of 20-degree pressure angle have any number of teeth from 28 to 36, inclusive. If it is considered necessary to leave enough stock on the gear teeth for a shaving or finishing cut, this allowance is simply added to the chordal dimension of the finished teeth to obtain the required measurement over the teeth for the roughing operation. It may be advisable to place this chordal dimension for rough machining on the detail drawing.

Formulas for Chordal Dimension M .— The required measurement M over spur gear teeth may be obtained by the following formula in which R = pitch radius of gear, A = pressure angle, T = tooth thickness along pitch circle, N = number of gear teeth, S = number of tooth spaces between caliper jaws, F = a factor depending on the pressure angle = 0.01109 for $14\frac{1}{2}^\circ$; = 0.01973 for $17\frac{1}{2}^\circ$; = 0.0298 for 20° ; = 0.04303 for $22\frac{1}{2}^\circ$; = 0.05995 for 25° . This factor F equals twice the involute function of the pressure angle.

$$M = R \times \cos A \times \left(\frac{T}{R} + \frac{6.2832 \times S}{N} + F \right)$$

Example: A spur gear has 30 teeth of 6 diametral pitch and a pressure angle of $14\frac{1}{2}$ degrees. Determine measurement M over three teeth, there being two intervening tooth spaces.

The pitch radius = $2\frac{1}{2}$ inches, the arc tooth thickness equivalent to 6 diametral pitch is 0.2618 inch (if no allowance is made for backlash) and factor F for $14\frac{1}{2}$ degrees = 0.01109 inch.

$$M = 2.5 \times 0.96815 \times \left(\frac{0.2618}{2.5} + \frac{6.2832 \times 2}{30} + 0.01109 \right) = 1.2941 \text{ inches}$$

PROPERTIES OF MATERIALS

Table 1. Standard Steel Classification

| Main Group | Content | Comments |
|------------------|--|---|
| Carbon Steels | When maximum content of the main elements do not exceed the following: Mn ≤ 1.65% Si ≤ 0.60% C ≤ 0.60% | May be used with or without final heat treatment. May be annealed, normalized, case hardened or quenched and tempered. May be killed ^a , semikilled, capped, or rimmed, and, when necessary, the method of deoxidation may be specified. |
| Alloy Steels | The maximum range of elements exceed the above amounts. Steels containing up to 3.99 % Cr, and smaller amounts (generally 1-4%) of other alloying elements. | Alloys steels are always killed, but special deoxidation or melting practices, including vacuum, may be specified for special critical applications. |
| Stainless Steels | Generally contains at least 10% Cr, with or without other elements. Few contain more than 30% Cr or less than 50% Fe. In the U.S. the stainless steel classification includes those steels containing 4% Cr. | In the broadest sense, this category can be divided into three groups based on structure: austenitic-(400 Series) nonmagnetic in the annealed condition. Nonhardenable; can be hardened by cold working. The general-purpose grade is widely known as 18-8 (Cr-Ni). ferritic-(400 Series) always magnetic and contain Cr but no Ni. Basic grade contains 17% Cr. This group also contains a 12% Cr steel with other elements, such as Al or Ti, added to prevent hardening. martensitic-(300 Series) Magnetic and can be hardened by quenching and tempering. Basic grade contains 12% Cr. This series contains more than 10 standard compositions that include small amounts of Ni and other elements. |

^akilled (defined)—Deoxidized with a strong deoxidizing agent such as silicon, aluminum or manganese in order to reduce the oxygen content to such a level that no reaction occurs between carbon and oxygen during solidification

Cr-chromium; Fe-iron; Si-silicon; C-copper; Mn-manganese; Ni-nickel; Ti-titanium

Table 2. Classification of Tool Steels

| Category Designation | Letter Symbol | Group Designation |
|-----------------------------|---------------|-----------------------------------|
| High-Speed Tool Steels | M | Molybdenum types |
| | T | Tungsten types |
| Hot-Work Tool Steels | H1–H19 | Chromium types |
| | H20–H39 | Tungsten types |
| Cold-Work Tool Steels | H40–H59 | Molybdenum types |
| | D | High-carbon, high-chromium types |
| | A | Medium-alloy, air-hardening types |
| Shock-Resisting Tool Steels | O | Oil-hardening types |
| | S | ... |
| Mold Steels | P | ... |
| Special-Purpose Tool Steels | L | Low-alloy types |
| | F | Carbon–tungsten types |
| Water-Hardening Tool Steels | W | ... |

Table 3. AISI-SAE System of Designating Carbon and Alloy Steels

| AISI-SAE Designation ^a | Type of Steel and Nominal Alloy Content (%) | |
|-----------------------------------|---|--|
| 10xx | Carbon Steels Plain Carbon (Mn 1.00% max.) | |
| 11xx | Resulfurized | |
| 12xx | Resulfurized and Rephosphorized | |
| 15xx | Plain Carbon (Max. Mn range 1.00 to 1.65%) | |
| 13xx | Manganese(Mn) Steels Mn 1.75 | |
| 23xx | Nickel(Ni) Steels Ni 3.50 | |
| 25xx | Ni 5.00 | |
| 31xx | Nickel(Ni)-Chromium(Cr) Steels Ni 1.25; Cr 0.65 and 0.80 | |
| 32xx | Ni 1.75; Cr 1.07 | |
| 33xx | Ni 3.50; Cr 1.50 and 1.57 | |
| 34xx | Ni 3.00; Cr 0.77 | |
| 40xx | Molybdenum (Mo) Steels Mo 0.20 and 0.25 | |
| 44xx | Mo 0.40 and 0.52 | |
| 41xx | Chromium(Cr)-Molybdenum(Mo) Steels Cr 0.50, 0.80, and 0.95; Mo 0.12, 0.20, 0.25, and 0.30 | |
| 43xx | Nickel(Ni)-Chromium(Cr)-Molybdenum(Mo) Steels Ni 1.82; Cr 0.50 and 0.80; Mo 0.25 | |
| 43BVxx | Ni 1.82; Cr 0.50; Mo 0.12 and 0.35; V 0.03 min. | |
| 47xx | Ni 1.05; Cr 0.45; Mo 0.20 and 0.35 | |
| 81xx | Ni 0.30; Cr 0.40; Mo 0.12 | |
| 86xx | Ni 0.55; Cr 0.50; Mo 0.20 | |
| 87xx | Ni 0.55; Cr 0.50; Mo 0.25 | |
| 88xx | Ni 0.55; Cr 0.50; Mo 0.35 | |
| 93xx | Ni 3.25; Cr 1.20; Mo 0.12 | |
| 94xx | Ni 0.45; Cr 0.40; Mo 0.12 | |
| 97xx | Ni 0.55; Cr 0.20; Mo 0.20 | |
| 98xx | Ni 1.00; Cr 0.80; Mo 0.25 | |
| 46xx | Nickel(Ni)-Molybdenum(Mo) Steels Ni 0.85 and 1.82; Mo 0.20 and 0.25 | |
| 48xx | Ni 3.50; Mo 0.25 | |
| 50xx | Chromium(Cr) Steels Cr 0.27, 0.40, 0.50, and 0.65 | |
| 51xx | Cr 0.80, 0.87, 0.92, 0.95, 1.00, and 1.05 | |
| 50xxx | Cr 0.50; C 1.00 min. | |
| 51xxx | Cr 1.02; C 1.00 min. | |
| 52xxx | Cr 1.45; C 1.00 min. | |
| 61xx | Chromium(Cr)-Vanadium(V) Steels Cr 0.60, 0.80, and 0.95; V 0.10 and 0.15 min | |
| 72xx | Tungsten(W)-Chromium(V) Steels W 1.75; Cr 0.75 | |
| 92xx | Silicon(Si)-Manganese(Mn) Steels Si 1.40 and 2.00; Mn 0.65, 0.82, and 0.85; Cr 0.00 and 0.65 | |
| 9xx | High-Strength Low-Alloy Steels Various SAE grades | |
| xxBxx | B denotes boron steels | |
| xxLxx | L denotes leaded steels | |
| AISI | SAE | Stainless Steels |
| 2xx | 302xx | Chromium(Cr)-Manganese(Mn)-Nickel(Ni) Steels |
| 3xx | 303xx | Chromium(Cr)-Nickel(Ni) Steels |
| 4xx | 514xx | Chromium(Cr) Steels |
| 5xx | 515xx | Chromium(Cr) Steels |

^axx in the last two digits of the carbon and low-alloy designations (but not the stainless steels) indicates that the carbon content (in hundredths of a per cent) is to be inserted.

Table 4. Classification, Approximate Compositions, and Properties Affecting Selection of Tool and Die Steels
 (From SAE Recommended Practice)

| Type of Tool Steel | Chemical Composition ^a | | | | | | | | Non-warping Prop. | Safety in Hardening | Toughness | Depth of Hardening | Wear Resistance |
|---|-----------------------------------|------|------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------------------|-------------------|--------------------|-----------------|
| | C | Mn | Si | Cr | V | W | Mo | Co | | | | | |
| Water Hardening | | | | | | | | | | | | | |
| 0.80 Carbon | 70–0.85 | b | b | b | ... | ... | ... | ... | Poor | Fair | Good ^c | Shallow | Fair |
| 0.90 Carbon | 0.85–0.95 | b | b | b | ... | ... | ... | ... | Poor | Fair | Good ^c | Shallow | Fair |
| 1.00 Carbon | 0.95–1.10 | b | b | b | ... | ... | ... | ... | Poor | Fair | Good ^c | Shallow | Good |
| 1.20 Carbon | 1.10–1.30 | b | b | b | ... | ... | ... | ... | Poor | Fair | Good ^c | Shallow | Good |
| 0.90 Carbon–V | 0.85–0.95 | b | b | b | 0.15–0.35 | ... | ... | ... | Poor | Fair | Good | Shallow | Fair |
| 1.00 Carbon–V | 0.95–1.10 | b | b | b | 0.15–0.35 | ... | ... | ... | Poor | Fair | Good | Shallow | Good |
| 1.00 Carbon–VV | 0.90–1.10 | b | b | b | 0.35–0.50 | ... | ... | ... | Poor | Fair | Good | Shallow | Good |
| Oil Hardening | | | | | | | | | | | | | |
| Low Manganese | 0.90 | 1.20 | 0.25 | 0.50 | 0.20 ^d | 0.50 | ... | ... | Good | Good | Fair | Deep | Good |
| High Manganese | 0.90 | 1.60 | 0.25 | 0.35 ^d | 0.20 ^d | ... | 0.30 ^d | ... | Good | Good | Fair | Deep | Good |
| High-Carbon, High-Chromium ^e | 2.15 | 0.35 | 0.35 | 12.00 | 0.80 ^d | 0.75 ^d | 0.80 ^d | ... | Good | Good | Poor | Through | Best |
| Chromium | 1.00 | 0.35 | 0.25 | 1.40 | ... | ... | 0.40 | ... | Fair | Good | Fair | Deep | Good |
| Molybdenum Graphitic | 1.45 | 0.75 | 1.00 | ... | ... | ... | 0.25 | ... | Fair | Good | Fair | Deep | Good |
| Nickel–Chromium ^f | 0.75 | 0.70 | 0.25 | 0.85 | 0.25 ^d | ... | 0.50 ^d | ... | Fair | Good | Fair | Deep | Fair |
| Air Hardening | | | | | | | | | | | | | |
| High-Carbon, High-Chromium | 1.50 | 0.40 | 0.40 | 12.00 | 0.80 ^d | ... | 0.90 | 0.60 ^d | Best | Best | Fair | Through | Best |
| 5 Per Cent Chromium | 1.00 | 0.60 | 0.25 | 5.25 | 0.40 ^d | ... | 1.10 | ... | Best | Best | Fair | Through | Good |
| High-Carbon, High-Chromium–Cobalt | 1.50 | 0.40 | 0.40 | 12.00 | 0.80 ^d | ... | 0.90 | 3.10 | Best | Best | Fair | Through | Best |
| Shock-Resisting | | | | | | | | | | | | | |
| Chromium–Tungsten | 0.50 | 0.25 | 0.35 | 1.40 | 0.20 | 2.25 | 0.40 ^d | ... | Fair | Good | Good | Deep | Fair |
| Silicon–Molybdenum | 0.50 | 0.40 | 1.00 | ... | 0.25 ^d | ... | 0.50 | ... | Poor ^g | Poor ^h | Best | Deep | Fair |
| Silicon–Manganese | 0.55 | 0.80 | 2.00 | 0.30 ^d | 0.25 ^d | ... | 0.40 ^d | ... | Poor ^g | Poor ^h | Best | Deep | Fair |
| Hot Work | | | | | | | | | | | | | |
| Chromium–Molybdenum–Tungsten | 0.35 | 0.30 | 1.00 | 5.00 | 0.25 ^d | 1.25 | 1.50 | ... | Good | Good | Good | Through | Fair |
| Chromium–Molybdenum–V | 0.35 | 0.30 | 1.00 | 5.00 | 0.40 | ... | 1.50 | ... | Good | Good | Good | Through | Fair |
| Chromium–Molybdenum–VV | 0.35 | 0.30 | 1.00 | 5.00 | 0.90 | ... | 1.50 | ... | Good | Good | Good | Through | Fair |

**Table 4. Classification, Approximate Compositions, and Properties Affecting Selection of Tool and Die Steels
(From SAE Recommended Practice)**

| Type of Tool Steel | Chemical Composition ^a | | | | | | | | Non-warping Prop. | Safety in Hardening | Toughness | Depth of Hardening | Wear Resistance |
|-------------------------------------|-----------------------------------|------|------|------|------|-------|------|-------|-------------------|---------------------|-----------|--------------------|-----------------|
| | C | Mn | Si | Cr | V | W | Mo | Co | | | | | |
| Tungsten | 0.32 | 0.30 | 0.20 | 3.25 | 0.40 | 9.00 | ... | ... | Good | Good | Good | Through | Fair |
| High Speed | | | | | | | | | | | | | |
| Tungsten, 18-4-1 | 0.70 | 0.30 | 0.30 | 4.10 | 1.10 | 18.00 | ... | ... | Good | Good | Poor | Through | Good |
| Tungsten, 18-4-2 | 0.80 | 0.30 | 0.30 | 4.10 | 2.10 | 18.50 | 0.80 | ... | Good | Good | Poor | Through | Good |
| Tungsten, 18-4-3 | 1.05 | 0.30 | 0.30 | 4.10 | 3.25 | 18.50 | 0.70 | ... | Good | Good | Poor | Through | Best |
| Cobalt-Tungsten, 14-4-2-5 | 0.80 | 0.30 | 0.30 | 4.10 | 2.00 | 14.00 | 0.80 | 5.00 | Good | Fair | Poor | Through | Good |
| Cobalt-Tungsten, 18-4-1-5 | 0.75 | 0.30 | 0.30 | 4.10 | 1.00 | 18.00 | 0.80 | 5.00 | Good | Fair | Poor | Through | Good |
| Cobalt-Tungsten, 18-4-2-8 | 0.80 | 0.30 | 0.30 | 4.10 | 1.75 | 18.50 | 0.80 | 8.00 | Good | Fair | Poor | Through | Good |
| Cobalt-Tungsten, 18-4-2-12 | 0.80 | 0.30 | 0.30 | 4.10 | 1.75 | 20.00 | 0.80 | 12.00 | Good | Fair | Poor | Through | Good |
| Molybdenum, 8-2-1 | 0.80 | 0.30 | 0.30 | 4.00 | 1.15 | 1.50 | 8.50 | ... | Good | Fair | Poor | Through | Good |
| Molybdenum-Tungsten, 6-6-2 | 0.83 | 0.30 | 0.30 | 4.10 | 1.90 | 6.25 | 5.00 | ... | Good | Fair | Poor | Through | Good |
| Molybdenum-Tungsten, 6-6-3 | 1.15 | 0.30 | 0.30 | 4.10 | 3.25 | 5.75 | 5.25 | ... | Good | Fair | Poor | Through | Best |
| Molybdenum-Tungsten, 6-6-4 | 1.30 | 0.30 | 0.30 | 4.25 | 4.25 | 5.75 | 5.25 | ... | Good | Fair | Poor | Through | Best |
| Cobalt-Molybdenum-Tungsten, 6-6-2-8 | 0.85 | 0.30 | 0.30 | 4.10 | 2.00 | 6.00 | 5.00 | 8.00 | Good | Fair | Poor | Through | Good |

^aC = carbon; Mn = manganese; Si = silicon; Cr = chromium; V = vanadium; W = tungsten; Mo = molybdenum; Co = cobalt.

^bCarbon tool steels are usually available in four grades or qualities: *Special (Grade 1)*—The highest quality water-hardening carbon tool steel, controlled for hardenability, chemistry held to closest limits, and subject to rigid tests to ensure maximum uniformity in performance; *Extra (Grade 2)*—A high-quality water-hardening carbon tool steel, controlled for hardenability, subject to tests to ensure good service; *Standard (Grade 3)*—A good-quality water-hardening carbon tool steel, not controlled for hardenability, recommended for application where some latitude with respect to uniformity is permissible; *Commercial (Grade 4)*—A commercial-quality water-hardening carbon tool steel, not controlled for hardenability, not subject to special tests. On *special* and *extra* grades, limits on manganese, silicon, and chromium are not generally required if Shepherd hardenability limits are specified. For *standard* and *commercial* grades, limits are 0.35 max. each for Mn and Si; 0.15 max. Cr for standard; 0.20 max. Cr for commercial.

^cToughness decreases somewhat when depth of hardening is increased.

^dOptional element. Steels have found satisfactory application either with or without the element present. In silicon-manganese steel listed under Shock-Resisting Steels, if chromium, vanadium, and molybdenum are not present, then hardenability will be affected.

^eThis steel may have 0.50 per cent nickel as an optional element. The steel has been found to give satisfactory application either with or without the element present.

^fApproximate nickel content of this steel is 1.50 per cent.

^gPoor when water quenched, fair when oil quenched.

^hPoor when water quenched, good when oil quenched.

Table 5. Quick Reference Guide for Tool Steel Selection

| Application Areas | Tool Steel Categories and AISI Letter Symbol | | | | | | |
|---|---|---|--|---|----------------|--------------------------------------|---|
| | High-Speed Tool Steels, M and T | Hot-Work Tool Steels, H | Cold-Work Tool Steels, D, A, and O | Shock-Resisting Tool Steels, S | Mold Steels, P | Special-Purpose Tool Steels, L and F | Water-Hardening Tool Steels, W |
| Examples of Typical Applications | | | | | | | |
| Cutting Tools Single-point types (lathe, planer, boring) Milling cutters Drills Reamers Taps Threading dies Form cutters | General purpose production tools: M2, T1 For increased abrasion resistance M3, M4, and M10 Heavy-duty work calling for high hot T5, T15 Heavy-duty work calling for high abrasion resistance: M42, M44 | | Tools with keen edges (knives, razors). Tools for operations where no high-speed is involved, yet stability in heat treatment and substantial abrasion resistance are needed | Pipe cutter wheels | | | Uses that do not require hot hardness or high abrasion resistance. Examples with carbon content of applicable group: Taps (1.05/1.10% C) Reamers (1.10/1.15% C) Twist drills (1.20/1.25% C) Files (1.35/1.40% C) |
| Hot Forging Tools and Dies Dies and inserts Forging machine plungers and pierces | To combine hot hardness with high abrasion resistance: M2, T1 | Dies for presses and hammers: H20, H21 For severe conditions over extended service periods: H22 to H26, also H43 | Hot trimming dies: D2 | Hot trimming dies Blacksmith tools Hot swaging dies | | | Smith's tools (1.65/0.70% C) Hot chisels (0.70/0.75% C) Drop forging dies (0.90/1.00% C) Applications limited to short run production |
| Hot Extrusion Tools and Dies Extrusion dies and mandrels, Dummy blocks Valve extrusion tools | Brass extrusion dies: T1 | Extrusion dies and dummy blocks: H20 to H26 For tools that are exposed to less heat: H10 to H19 | | Compression molding: S1 | | | |

Table 5. Quick Reference Guide for Tool Steel Selection

| Application Areas | Tool Steel Categories and AISI Letter Symbol | | | | | | |
|---|---|---|--|---|-----------------------------------|--|---|
| | High-Speed Tool Steels, M and T | Hot-Work Tool Steels, H | Cold-Work Tool Steels, D, A, and O | Shock-Resisting Tool Steels, S | Mold Steels, P | Special-Purpose Tool Steels, L and F | Water-Hardening Tool Steels, W |
| Examples of Typical Applications | | | | | | | |
| Cold-Forming Dies Bending, forming, drawing, and deep drawing dies and punches | Burnishing tools: M1, T1 | Cold heading: die casting dies: H13 | Drawing dies: O1 Coining tools: O1, D2 Forming and bending dies: A2 Thread rolling dies: D2 | Hobbing and short-run applications: S1, S7 Rivet sets and rivet busters | | Blanking, forming, and trimmer dies when toughness has precedence over abrasion resistance: L6 | Cold-heading dies: W1 or W2 (C ≈ 1.00%) Bending dies: W1 (C ≈ 1.00%) |
| Shearing Tools Dies for piercing, punching, and trimming Shear blades | Special dies for cold and hot work: T1 For work requiring high abrasion resistance: M2, M3 | For shearing knives: H11, H12 For severe hot shearing applications: M21, M25 | Dies for medium runs: A2, A6 also O1 and O4 Dies for long runs: D2, D3 Trimming dies (also for hot trimming): A2 | Cold and hot shear blades Hot punching and piercing tools Boilermaker's tools | | Knives for work requiring high toughness: L6 | Trimming dies (0.90/0.95% C) Cold blanking and punching dies (1.00% C) |
| Die Casting Dies and Plastics Molds | | For aluminum and lead: H11 and H13 For brass: H21 | A2 and A6 O1 | | Plastics molds: P2 to P4, and P20 | | |
| Structural Parts for Severe Service Conditions | Roller bearings for high-temperature environment: T1 Lathe centers: M2 and T1 | For aircraft components (landing gear, arrester hooks, rocket cases): H11 | Lathe centers: D2, D3 Arbors: O1 Bushings: A4 Gages: D2 | Pawl Clutch parts | | Spindles, clutch parts (where high toughness is needed): L6 | Spring steel (1.10/1.15% C) |
| Battering Tools for Hand and Power Tool Use | | | | Pneumatic chisels for cold work: S5 For higher performance: S7 | | | For intermittent use: W1 (0.80% C) |

Table 6. Molybdenum High-Speed Tool Steels

Table 7. Hot-Work Tool Steels

| Identifying Chemical Composition and Typical Heat-Treatment Data | | | | | | | | | | | | | | | | | | |
|--|--------------------------------------|------------------|----------------|-----------|-----------|-----------|-----------|-----------|----------------|-----------|-----------|-----------|-----------|-----------|------------------|-----------|-----------|-----------|
| AISI | Group | | Chromium Types | | | | | | Tungsten Types | | | | | | Molybdenum Types | | | |
| | Type | | H10 | H11 | H12 | H13 | H14 | H19 | H21 | H22 | H23 | H24 | H25 | H26 | H41 | H42 | H43 | |
| Identifying Chemical Elements in Per Cent | C | | 0.40 | 0.35 | 0.35 | 0.35 | 0.40 | 0.40 | 0.35 | 0.35 | 0.35 | 0.45 | 0.25 | 0.50 | 0.65 | 0.60 | 0.55 | |
| | W | | ... | .. | 1.50 | ... | 5.00 | 4.25 | 9.00 | 11.00 | 12.00 | 15.00 | 15.00 | 18.00 | 1.50 | 6.00 | ... | |
| | Mo | | 2.50 | 1.50 | 1.50 | 1.50 | ... | ... | ... | ... | ... | ... | ... | ... | 8.00 | 5.00 | 8.00 | |
| | Cr | | 3.25 | 5.00 | 5.00 | 5.00 | 5.00 | 4.25 | 3.50 | 2.00 | 12.00 | 3.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | |
| | V | | 0.40 | 0.40 | 0.40 | 1.00 | ... | 2.00 | ... | ... | ... | ... | ... | 1.00 | 1.00 | 2.00 | 2.00 | |
| | Co | | ... | ... | ... | ... | ... | 4.25 | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| Heat-Treat. Data | Hardening Temperature Range, °F | | | 1850–1900 | 1825–1875 | 1825–1875 | 1825–1900 | 1850–1950 | 2000–2200 | 2000–2200 | 2000–2200 | 2000–2300 | 2000–2250 | 2100–2300 | 2150–2300 | 2000–2175 | 2050–2225 | 2000–2175 |
| | Tempering Temperature Range, °F | | | 1000–1200 | 1000–1200 | 1000–1200 | 1000–1200 | 1100–1200 | 1000–1300 | 1100–1250 | 1100–1250 | 1200–1500 | 1050–1200 | 1050–1250 | 1050–1250 | 1050–1200 | 1050–1200 | 1050–1200 |
| | Approx. Tempered Hardness, Rc | | | 56–39 | 54–38 | 55–38 | 53–38 | 47–40 | 59–40 | 54–36 | 52–39 | 47–30 | 55–45 | 44–35 | 58–43 | 60–50 | 60–50 | 58–45 |
| Relative Ratings of Properties (A = greatest to D = least) | | | | | | | | | | | | | | | | | | |
| Characteristics in Heat Treatment | Safety in Hardening | | | A | A | A | A | A | B | B | B | B | B | B | C | C | C | |
| | Depth of Hardening | | | A | A | A | A | A | A | A | A | A | A | A | A | A | A | |
| | Resistance to Decarburization | | | B | B | B | B | B | B | B | B | B | B | B | C | B | C | |
| | Stability of Shape in Heat Treatment | Quenching Medium | Air or Salt | B | B | B | B | C | C | C | C | ... | C | C | C | C | C | |
| | | | Oil | ... | ... | ... | ... | ... | D | D | D | D | D | D | D | D | D | |
| Service Properties | Machinability | | | C/D | C/D | C/D | C/D | D | D | D | D | D | D | D | D | D | D | |
| | Hot Hardness | | | C | C | C | C | C | C | C | B | B | B | B | B | B | B | |
| | Wear Resistance | | | D | D | D | D | D | C/D | C/D | C/D | C/D | C | D | C | C | C | |
| | Toughness | | | C | B | B | B | C | C | C | C | D | D | C | D | D | D | |

Table 8. Tungsten High-Speed Tool Steels

| Identifying Chemical Composition and Typical Heat-Treatment Data | | | | | | | | | | |
|--|---|------------------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Identifying Chemical Elements in Per Cent | AISI Type | | T1 | T2 | T4 | T5 | T6 | T8 | T15 | |
| | C | | 0.75 | 0.80 | 0.75 | 0.80 | 0.80 | 0.75 | 1.50 | |
| | W | | 18.00 | 18.00 | 18.00 | 18.00 | 20.00 | 14.00 | 12.00 | |
| | Cr | | 4.00 | 4.00 | 4.00 | 4.00 | 4.50 | 4.00 | 4.00 | |
| | V | | 1.00 | 2.00 | 1.00 | 2.00 | 1.50 | 2.00 | 5.00 | |
| | Co | | ... | ... | 5.00 | ... | ... | 5.00 | 5.00 | |
| Heat-Treatment Data | Hardening Temperature Range, °F | | | 2300–2375 | 2300–2375 | 2300–2375 | 2325–2375 | 2325–2375 | 2300–2375 | 2200–2300 |
| | Tempering Temperature Range, °F | | | 1000–1100 | 1000–1100 | 1000–1100 | 1000–1100 | 1000–1100 | 1000–1100 | 1000–1200 |
| | Approx. Tempered Hardness, R _c | | | 65–60 | 66–61 | 66–62 | 65–60 | 65–60 | 65–60 | 68–63 |
| Relative Ratings of Properties (A = greatest to E = least) | | | | | | | | | | |
| Characteristics in Heat Treatment | Safety in Hardening | | | C | C | D | D | D | D | |
| | Depth of Hardening | | | A | A | A | A | A | A | |
| | Resistance to Decarburization | | | A | A | B | C | C | B | |
| | Stability of Shape in Heat Treatment | Quenching Medium | Air or Salt | C | C | C | C | C | C | |
| | | Oil | D | D | D | D | D | D | D | |
| Service Properties | Machinability | | | D | D | D | D/E | D | D/E | |
| | Hot Hardness | | | B | B | A | A | A | A | |
| | Wear Resistance | | | B | B | B | B | B | A | |
| | Toughness | | | E | E | E | E | E | E | |

Table 9. Cold-Work Tool Steels

| Identifying Chemical Composition and Typical Heat-Treatment Data | | | | | | | | | | | | | | | | | | | |
|--|--------------------------------------|----------------------------------|-----------|-----------|-----------|-----------|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|---------------------|-----------|-----------|-----------|-----------|------|
| AISI | Group | High-Carbon, High-Chromium Types | | | | | Medium-Alloy, Air-Hardening Types | | | | | | | Oil-Hardening Types | | | | | |
| | Types | D2 | D3 | D4 | D5 | D7 | A2 | A3 | A4 | A6 | A7 | A8 | A9 | A10 | O1 | O2 | O6 | O7 | |
| Identifying Chemical Elements in Per Cent | C | 1.50 | 2.25 | 2.25 | 1.50 | 2.35 | 1.00 | 1.25 | 1.00 | 0.70 | 2.25 | 0.55 | 0.50 | 1.35 | 0.90 | 0.90 | 1.45 | 1.20 | |
| | Mn | ... | ... | ... | ... | ... | ... | ... | 2.00 | 2.00 | ... | ... | ... | 1.80 | 1.00 | 1.60 | ... | ... | |
| | Si | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1.25 | ... | ... | 1.00 | ... | |
| | W | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1.00 | 1.25 | 1.00 | 1.25 | 1.40 | 1.50 | 0.50 | ... | 1.75 |
| | Mo | 1.00 | ... | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.25 | 1.00 | 1.25 | 1.40 | 1.50 | ... | ... | 0.25 | ... | |
| | Cr | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 5.00 | 5.00 | 1.00 | 1.00 | 5.25 | 5.00 | 5.00 | ... | 0.50 | ... | ... | 0.75 | |
| | V | 1.00 | ... | ... | ... | 4.00 | ... | 1.00 | ... | ... | 4.75 | ... | 1.00 | ... | ... | ... | ... | ... | |
| | Co | ... | ... | ... | 3.00 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| Heat-Treatment Data | Ni | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1.50 | 1.80 | ... | ... | ... | |
| | Hardening Temperature Range, °F | 1800–1875 | 1700–1800 | 1775–1850 | 1800–1875 | 1850–1950 | 1700–1800 | 1750–1850 | 1500–1600 | 1525–1600 | 1750–1800 | 1800–1850 | 1800–1875 | 1450–1500 | 1450–1500 | 1400–1475 | 1450–1500 | 1550–1525 | |
| | Quenching Medium | Air | Oil | Air | Air | Air | Air | Air | Air | Air | Air | Air | Air | Oil | Oil | Oil | Oil | | |
| | Tempering Temperature Range, °F | 400–1000 | 400–1000 | 400–1000 | 400–1000 | 300–1000 | 350–1000 | 350–800 | 300–800 | 300–1000 | 350–1100 | 950–1150 | 350–800 | 350–500 | 350–500 | 350–600 | 350–550 | | |
| | Approx. Tempered Hardness, Rc | 61–54 | 61–54 | 61–54 | 61–54 | 65–58 | 62–57 | 65–57 | 62–54 | 60–54 | 67–57 | 60–50 | 56–35 | 62–55 | 62–57 | 62–57 | 63–58 | 64–58 | |
| Relative Ratings of Properties (A = greatest to E = least) | | | | | | | | | | | | | | | | | | | |
| Characteristics in Heat Treatment | Safety in Hardening | A | C | A | A | A | A | A | A | A | A | A | A | B | B | B | B | | |
| | Depth of Hardening | A | A | A | A | A | A | A | A | A | A | A | A | B | B | B | B | | |
| | Resistance to Decarburization | B | B | B | B | B | B | A/B | A/B | B | B | B | A/B | A | A | A | A | | |
| | Stability of Shape in Heat Treatment | A | B | A | A | A | A | A | A | A | A | A | A | B | B | B | B | | |
| Service Properties | Machinability | E | E | E | E | E | D | D | D/E | D/E | E | D | D | C/D | C | C | B | C | |
| | Hot Hardness | C | C | C | C | C | C | D | D | C | C | C | D | E | E | E | E | | |
| | Wear Resistance | B/C | B | B | B/C | A | C | B | C/D | C/D | A | C/D | C/D | C | D | D | D | | |
| | Toughness | E | E | E | E | E | D | D | D | D | E | C | C | D | D | D | C | | |

Table 10. Shock-Resisting, Mold, and Special-Purpose Tool Steels

| Identifying Chemical Composition and Typical Heat-Treatment Data | | | | | | | | | | | | | | | | | | | | |
|--|--------------------------------------|--------------|-----------------------------|-----------|-----------|-----------|-------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------------------|-----------------|-----------------|-----------|-----------|-----------|-----------|--|
| AISI | Category | | Shock-Resisting Tool Steels | | | | Mold Steels | | | | | | Special-Purpose Tool Steels | | | | | | | |
| | Types | | S1 | S2 | S5 | S7 | P2 | P3 | P4 | P5 | P6 | P20 | P21 ^a | L2 ^b | L3 ^b | L6 | F1 | F2 | | |
| Identifying Elements in Percent | C | | 0.50 | 0.50 | 0.55 | 0.50 | 0.07 | 0.10 | 0.07 | 0.10 | 0.10 | 0.35 | 0.20 | 0.50/ 1.10 | 1.00 | 0.70 | 1.00 | 1.25 | | |
| | Mn | | ... | ... | 0.80 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| | Si | | ... | 1.00 | 2.00 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| | W | | 2.50 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1.25 | 3.50 | | |
| | Mo | | ... | 0.50 | 0.40 | 1.40 | 0.20 | ... | 0.75 | ... | ... | 0.40 | ... | ... | ... | 0.25 | ... | ... | | |
| | Cr | | 1.50 | ... | ... | 3.25 | 2.00 | 0.60 | 5.00 | 2.25 | 1.50 | 1.25 | ... | 1.00 | 1.50 | 0.75 | ... | ... | | |
| | V | | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.20 | 0.20 | ... | ... | | |
| | Ni | | ... | ... | ... | ... | 0.50 | 1.25 | ... | ... | 3.50 | ... | 4.00 | ... | ... | 1.50 | ... | ... | | |
| Heat-Treat. Data | Hardening Temperature, °F | | | 1650–1750 | 1550–1650 | 1600–1700 | 1700–1750 | 1525–1550 ^c | 1475–1525 ^c | 1775–1825 ^c | 1550–1600 ^c | 1450–1500 ^c | 1500–1600 ^c | Soln. treat. | 1550–1700 | 1500–1600 | 1450–1550 | 1450–1600 | 1450–1600 | |
| | Tempering Temp. Range, °F | | | 400–1200 | 350–800 | 350–800 | 400–1150 | 350–500 | 350–500 | 350–900 | 350–500 | 350–450 | 900–1100 | Aged | 350–1000 | 350–600 | 350–1000 | 350–500 | 350–500 | |
| | Approx. Tempered Hardness, Rc | | | 58–40 | 60–50 | 60–50 | 57–45 | 64–58 ^d | 64–58 ^d | 64–58 ^d | 64–58 ^d | 61–58 ^d | 37–28 ^d | 40–30 | 63–45 | 63–56 | 62–45 | 64–60 | 65–62 | |
| Relative Ratings of Properties (A = greatest to E = least) | | | | | | | | | | | | | | | | | | | | |
| Characteristics in Heat Treatment | Safety in Hardening | | | C | E | C | B/C | C | C | C | C | C | C | A | D | D | C | E | E | |
| | Depth of Hardening | | | B | B | B | A | B ^e | B ^e | B ^e | B ^e | A ^e | B | A | B | B | B | C | C | |
| | Resist. to Decarburization | | | B | C | C | B | A | A | A | A | A | A | A | A | A | A | A | A | |
| | Stability of Shape in Heat Treatment | Quench. Med. | Air | ... | ... | ... | A | ... | ... | B | ... | B | C | A | ... | ... | ... | ... | ... | |
| | | | Oil | D | ... | D | C | C | C | ... | C | C | ... | A | D | D | C | ... | ... | |
| | | | Water ^f | ... | E | ... | ... | ... | ... | E | ... | ... | ... | E | E | ... | E | E | ... | |
| Service Properties | Machinability | | | D | C/D | C/D | D | C/D | D | D/E | D | D | C/D | D | C | C | D | C | D | |
| | Hot Hardness | | | D | E | E | C | E | E | D | E | E | E | D | E | E | E | E | E | |
| | Wear Resistance | | | D/E | D/E | D/E | D/E | D | D | C | D | D | D/E | D | D/E | D | D | D | B/C | |
| | Toughness | | | B | A | A | B | C | C | C | C | C | C | D | B | D | B | E | E | |

^aContains also about 1.20 per cent A1. Solution treated in hardening.^bQuenched in oil.^cAfter carburizing.^dCarburized case.^eCore hardenability.^fSometimes brine is used.

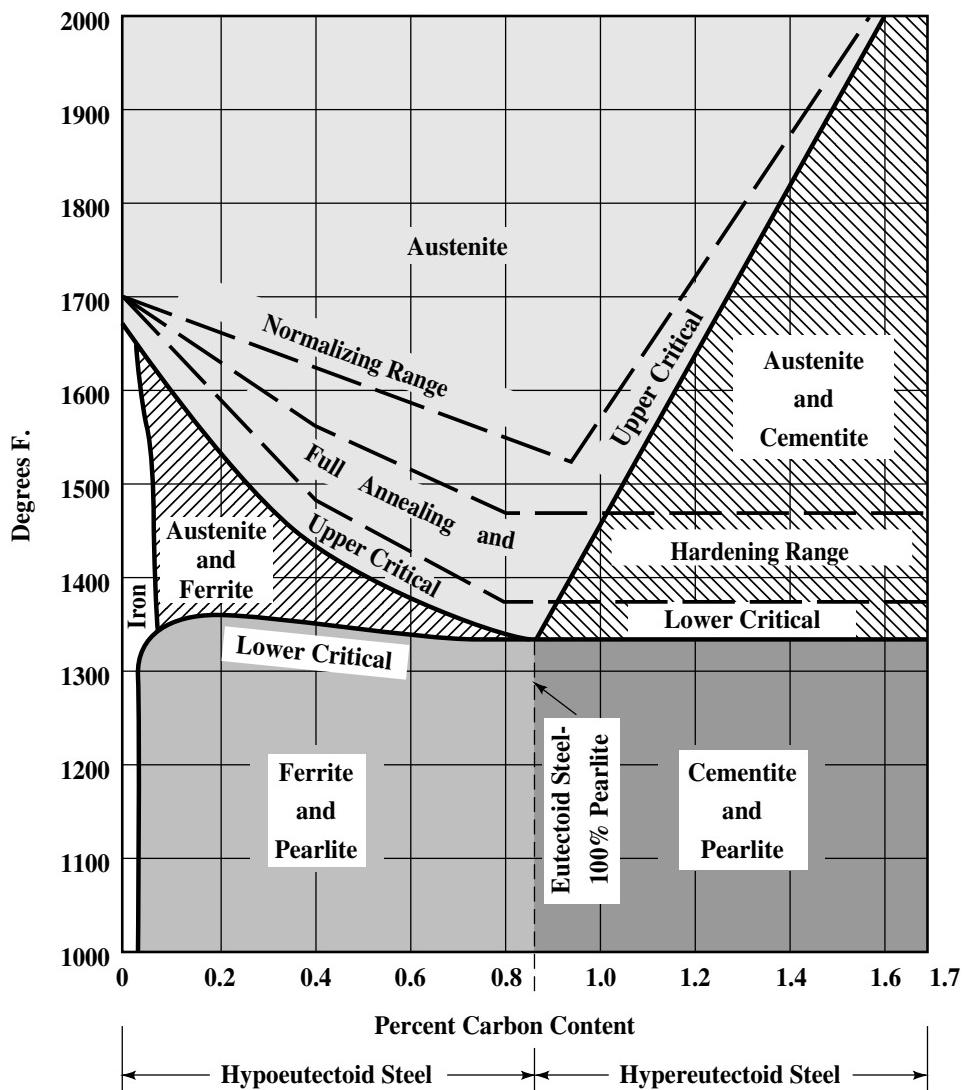


Fig. 1. Phase Diagram of Carbon Steel

Table 11. Temperature of Steel as Indicated by Color Related to Heat Treatment of Steel Cutting Tools

| Temperature | | Color of Steel | Processes and Tool Tempering Temperatures |
|-------------|-----|------------------|--|
| °F | °C | | |
| 420 | 216 | Faint yellow | Carbon tool steel tempering (300-1050F), hammer heads, thin knife blades, razors, wood engraving burins, scribes. |
| 430 | 221 | Very pale yellow | Carbon tool steel tempering, reamers, hollow mills (solid type) for roughing on automatic screw machine, forming tools for automatic screw machine, cut off tools for automatic screw machine, formed milling cutters. |
| 440 | 227 | Light yellow | Carbon tool steel tempering, lathe tools, milling cutters, reamers, profile cutters for milling machine (440-450F), drill bits (400-445 F) |

**Table 11. Temperature of Steel as Indicated by Color
Related to Heat Treatment of Steel Cutting Tools**

| Temperature | | Color of Steel | Processes and Tool Tempering Temperatures |
|-------------|---------|--|--|
| °F | °C | | |
| 450 | 232 | Pale straw-yellow | Carbon tool steel tempering, razors, twist drills for hard service, centering tools for automatic screw machine, hatchets and axes |
| 460 | 238 | Straw-yellow | Carbon tool steel tempering, drill bits, dies, punches, reamers, thread rolling dies, counterbores and countersinks, snaps for pneumatic hammers (harden full length, temper to 460F, then bring point to 520F). |
| 470 | 243 | Deep straw-yellow | Carbon tool steel tempering, various kinds of wood cutting tools (470-490F) |
| 480 | 249 | Dark yellow | Carbon tool steel tempering, drills, taps, knurls (485F), cutters for tube or pipe-cutting machine. |
| 490 | 254 | Yellowish-brown | Carbon tool steel tempering. Thread dies for tool steel or steel tube (495F), cold chisels, stone carving tools, punches, dies. |
| 500 | 260 | Brown-yellow | Carbon tool steel tempering, wood (chipping) chisels, saws, drifts, thread dies for general work, taps 1 inch or over, for use on automatic screw machines, nut taps 1 inch and under. |
| 510 | 266 | Spotted red-brown | Carbon tool steel tempering, taps 1 inch and under, for use on automatic screw machines (515-520F) |
| 520 | 271 | Brown-purple | Carbon tool steel tempering |
| 530 | 277 | Light purple | Carbon tool steel tempering, percussive tools, thread dies to cut thread close to shoulder (525-530F), dies for bolt threader threading to shoulder (525-540F) |
| 540 | 282 | Full purple | Carbon tool steel tempering, punches (center), wood-carving gouges |
| 550 | 288 | Dark purple/violet | Carbon tool steel tempering, spatulas, table knives, shear blades |
| 560 | 293 | Full blue | Carbon tool steel tempering, gears, screwdriver blades, springs |
| 570 | 299 | Dark blue | Carbon tool steel tempering, springs |
| 600 | 316 | Medium blue | Carbon tool steel tempering, springs, spokeshave blades, scrapers, thin knife blades (580-650F), rivet snaps (575-600F) |
| 640 | 338 | Light blue | Carbon tool steel tempering, springs (650-900F), for hard parts |
| 700-800 | 371-427 | Black red-visible in low light or dark | Carbon tool steel tempering |
| 885 | 474 | Red-visible at twilight | Carbon tool steel tempering |
| 975 | 523.9 | Red-visible in daylight | Carbon tool steel tempering |
| 1000 | 538 | Very dark red-visible in daylight | Carbon tool steel tempering High Speed Steel tempering (1000-1100F) |
| 1100 | 593 | Dark red-visible in sunlight | High Speed Steel tempering |
| 1300 | 704 | Dark red | |
| 1400 | 760 | Dark cherry red | Carbon tool steel hardening (1350-1550F) |
| 1475 | 802 | Dull cherry red | Carbon tool steel hardening |
| 1550 | 843 | Light cherry-red | Alloy tool steel hardening (1500-1950F) |
| 1650 | 899 | Cherry-red | Alloy tool steel hardening |
| 1800 | 982 | Orange-red | Alloy tool steel hardening |
| 2000 | 1093 | Yellow | |
| 2300 | 1260 | Yellow-white | High Speed Steel Hardening (2250-2400F) |
| 2400 | 1316 | White | High Speed Steel Hardening |
| 2500 | 1371 | White | Welding |
| 2750 | 1590 | Brilliant white | |
| 3000 | 1649 | Dazzling blue-white | |

Table 12. Comparative Hardness Scales for Steel

| Rockwell C-Scale Hardness Number | Diamond Pyramid Hardness Number Vickers | Brinell Hardness Number 10-mm Ball, 3000-kgf Load | | | Rockwell Hardness Number | | Rockwell Hardness Number Superficial Diam. Penetrator | | | Shore Sclero- scope Hard- ness Num- ber |
|---|---|---|------------------|-----------------------------|--|---|--|---------------------------------|---------------------------------|---|
| | | Standard Ball | Hultgren Ball | Tungsten Carbide Ball | A-Scale 60-kgf LoadDiam. Penetrator | D-Scale 100-kgf LoadDiam. Penetrator | 15-N Scale 15-kgf Load | 30-N Scale 30-kgf Load | 45-N Scale 45-kgf Load | |
| 68 | 940 | ... | ... | ... | 85.6 | 76.9 | 93.2 | 84.4 | 75.4 | 97 |
| 67 | 900 | ... | ... | ... | 85.0 | 76.1 | 92.9 | 83.6 | 74.2 | 95 |
| 66 | 865 | ... | ... | ... | 84.5 | 75.4 | 92.5 | 82.8 | 73.3 | 92 |
| 65 | 832 | ... | ... | 739 | 83.9 | 74.5 | 92.2 | 81.9 | 72.0 | 91 |
| 64 | 800 | ... | ... | 722 | 83.4 | 73.8 | 91.8 | 81.1 | 71.0 | 88 |
| 63 | 772 | ... | ... | 705 | 82.8 | 73.0 | 91.4 | 80.1 | 69.9 | 87 |
| 62 | 746 | ... | ... | 688 | 82.3 | 72.2 | 91.1 | 79.3 | 68.8 | 85 |
| 61 | 720 | ... | ... | 670 | 81.8 | 71.5 | 90.7 | 78.4 | 67.7 | 83 |
| 60 | 697 | ... | 613 | 654 | 81.2 | 70.7 | 90.2 | 77.5 | 66.6 | 81 |
| 59 | 674 | ... | 599 | 634 | 80.7 | 69.9 | 89.8 | 76.6 | 65.5 | 80 |
| 58 | 653 | ... | 587 | 615 | 80.1 | 69.2 | 89.3 | 75.7 | 64.3 | 78 |
| 57 | 633 | ... | 575 | 595 | 79.6 | 68.5 | 88.9 | 74.8 | 63.2 | 76 |
| 56 | 613 | ... | 561 | 577 | 79.0 | 67.7 | 88.3 | 73.9 | 62.0 | 75 |
| 55 | 595 | ... | 546 | 560 | 78.5 | 66.9 | 87.9 | 73.0 | 60.9 | 74 |
| 54 | 577 | ... | 534 | 543 | 78.0 | 66.1 | 87.4 | 72.0 | 59.8 | 72 |
| 53 | 560 | ... | 519 | 525 | 77.4 | 65.4 | 86.9 | 71.2 | 58.6 | 71 |
| 52 | 544 | 500 | 508 | 512 | 76.8 | 64.6 | 86.4 | 70.2 | 57.4 | 69 |
| 51 | 528 | 487 | 494 | 496 | 76.3 | 63.8 | 85.9 | 69.4 | 56.1 | 68 |
| 50 | 513 | 475 | 481 | 481 | 75.9 | 63.1 | 85.5 | 68.5 | 55.0 | 67 |
| 49 | 498 | 464 | 469 | 469 | 75.2 | 62.1 | 85.0 | 67.6 | 53.8 | 66 |
| 48 | 484 | 451 | 455 | 455 | 74.7 | 61.4 | 84.5 | 66.7 | 52.5 | 64 |
| 47 | 471 | 442 | 443 | 443 | 74.1 | 60.8 | 83.9 | 65.8 | 51.4 | 63 |
| 46 | 458 | 432 | 432 | 432 | 73.6 | 60.0 | 83.5 | 64.8 | 50.3 | 62 |
| 45 | 446 | 421 | 421 | 421 | 73.1 | 59.2 | 83.0 | 64.0 | 49.0 | 60 |
| 44 | 434 | 409 | 409 | 409 | 72.5 | 58.5 | 82.5 | 63.1 | 47.8 | 58 |
| 43 | 423 | 400 | 400 | 400 | 72.0 | 57.7 | 82.0 | 62.2 | 46.7 | 57 |
| 42 | 412 | 390 | 390 | 390 | 71.5 | 56.9 | 81.5 | 61.3 | 45.5 | 56 |
| 41 | 402 | 381 | 381 | 381 | 70.9 | 56.2 | 80.9 | 60.4 | 44.3 | 55 |
| 40 | 392 | 371 | 371 | 371 | 70.4 | 55.4 | 80.4 | 59.5 | 43.1 | 54 |
| 39 | 382 | 362 | 362 | 362 | 69.9 | 54.6 | 79.9 | 58.6 | 41.9 | 52 |
| 38 | 372 | 353 | 353 | 353 | 69.4 | 53.8 | 79.4 | 57.7 | 40.8 | 51 |
| 37 | 363 | 344 | 344 | 344 | 68.9 | 53.1 | 78.8 | 56.8 | 39.6 | 50 |
| 36 | 354 | 336 | 336 | 336 | 68.4 | 52.3 | 78.3 | 55.9 | 38.4 | 49 |
| 35 | 345 | 327 | 327 | 327 | 67.9 | 51.5 | 77.7 | 55.0 | 37.2 | 48 |
| 34 | 336 | 319 | 319 | 319 | 67.4 | 50.8 | 77.2 | 54.2 | 36.1 | 47 |
| 33 | 327 | 311 | 311 | 311 | 66.8 | 50.0 | 76.6 | 53.3 | 34.9 | 46 |
| 32 | 318 | 301 | 301 | 301 | 66.3 | 49.2 | 76.1 | 52.1 | 33.7 | 44 |
| 31 | 310 | 294 | 294 | 294 | 65.8 | 48.4 | 75.6 | 51.3 | 32.5 | 43 |
| 30 | 302 | 286 | 286 | 286 | 65.3 | 47.7 | 75.0 | 50.4 | 31.3 | 42 |
| 29 | 294 | 279 | 279 | 279 | 64.7 | 47.0 | 74.5 | 49.5 | 30.1 | 41 |
| 28 | 286 | 271 | 271 | 271 | 64.3 | 46.1 | 73.9 | 48.6 | 28.9 | 41 |
| 27 | 279 | 264 | 264 | 264 | 63.8 | 45.2 | 73.3 | 47.7 | 27.8 | 40 |
| 26 | 272 | 258 | 258 | 258 | 63.3 | 44.6 | 72.8 | 46.8 | 26.7 | 38 |
| 25 | 266 | 253 | 253 | 253 | 62.8 | 43.8 | 72.2 | 45.9 | 25.5 | 38 |
| 24 | 260 | 247 | 247 | 247 | 62.4 | 43.1 | 71.6 | 45.0 | 24.3 | 37 |
| 23 | 254 | 243 | 243 | 243 | 62.0 | 42.1 | 71.0 | 44.0 | 23.1 | 36 |
| 22 | 248 | 237 | 237 | 237 | 61.5 | 41.6 | 70.5 | 43.2 | 22.0 | 35 |
| 21 | 243 | 231 | 231 | 231 | 61.0 | 40.9 | 69.9 | 42.3 | 20.7 | 35 |
| 20 | 238 | 226 | 226 | 226 | 60.5 | 40.1 | 69.4 | 41.5 | 19.6 | 34 |
| (18) | 230 | 219 | 219 | 219 | ... | ... | ... | ... | ... | 33 |
| (16) | 222 | 212 | 212 | 212 | ... | ... | ... | ... | ... | 32 |
| (14) | 213 | 203 | 203 | 203 | ... | ... | ... | ... | ... | 31 |
| (12) | 204 | 194 | 194 | 194 | ... | ... | ... | ... | ... | 29 |
| (10) | 196 | 187 | 187 | 187 | ... | ... | ... | ... | ... | 28 |
| (8) | 188 | 179 | 179 | 179 | ... | ... | ... | ... | ... | 27 |
| (6) | 180 | 171 | 171 | 171 | ... | ... | ... | ... | ... | 26 |
| (4) | 173 | 165 | 165 | 165 | ... | ... | ... | ... | ... | 25 |
| (2) | 166 | 158 | 158 | 158 | ... | ... | ... | ... | ... | 24 |
| (0) | 160 | 152 | 152 | 152 | ... | ... | ... | ... | ... | 24 |

Note: The values in this table shown in **boldface** type correspond to those shown in American Society for Testing and Materials Specification E140-67. Values in () are beyond the normal range and are given for information only.

Table 13. Comparative Hardness Scales for Unhardened Steel, Soft-Temper Steel, Grey and Malleable Cast Iron, and Nonferrous Alloys

| Rockwell Hardness Number | | | Rockwell Superficial Hardness Number | | | Rockwell Hardness Number | | | Brinell Hardness Number | |
|--|---|--|--|--|--|---|---|--|--|---|
| Rockwell B scale 1/16" Ball Penetrator 100-kg Load | Rockwell F scale 1/16" Ball Penetrator 60-kg Load | Rockwell G scale 1/16" Ball Penetrator 150-kg Load | Rockwell Superficial 15-T scale 1/16" Ball Penetrator | Rockwell Superficial 30-T scale 1/16" Ball Penetrator | Rockwell Superficial 45-T scale 1/16" Ball Penetrator | Rockwell E scale 1/8" Ball Penetrator 100-kg Load | Rockwell K scale 1/8" Ball Penetrator 150-kg Load | Rockwell A scale "Brale" Penetrator 60-kg Load | Brinell Scale 10-mm Standard Ball 500-kg Load | Brinell Scale 10-mm Standard Ball 3000-kg Load |
| 100 | | 82.5 | 93.0 | 82.0 | 72.0 | | | 61.5 | 201 | 240 |
| 99 | | 81.0 | 92.5 | 81.5 | 71.0 | | | 61.0 | 195 | 234 |
| 98 | | 79.0 | ... | 81.0 | 70.0 | | | 60.0 | 189 | 228 |
| 97 | | 77.5 | 92.0 | 80.5 | 69.0 | | | 59.5 | 184 | 222 |
| 96 | | 76.0 | ... | 80.0 | 68.0 | | | 59.0 | 179 | 216 |
| 95 | | 74.0 | 91.5 | 79.0 | 67.0 | | | 58.0 | 175 | 210 |
| 94 | | 72.5 | ... | 78.5 | 66.0 | | | 57.5 | 171 | 205 |
| 93 | | 71.0 | 91.0 | 78.0 | 65.5 | | | 57.0 | 167 | 200 |
| 92 | | 69.0 | 90.5 | 77.5 | 64.5 | | 100 | 56.5 | 163 | 195 |
| 91 | | 67.5 | ... | 77.0 | 63.5 | | 99.5 | 56.0 | 160 | 190 |
| 90 | | 66.0 | 90.0 | 76.0 | 62.5 | | 98.5 | 55.5 | 157 | 185 |
| 89 | | 64.0 | 89.5 | 75.5 | 61.5 | | 98.0 | 55.0 | 154 | 180 |
| 88 | | 62.5 | ... | 75.0 | 60.5 | | 97.0 | 54.0 | 151 | 176 |
| 87 | | 61.0 | 89.0 | 74.5 | 59.5 | | 96.5 | 53.5 | 148 | 172 |
| 86 | | 59.0 | 88.5 | 74.0 | 58.5 | | 95.5 | 53.0 | 145 | 169 |
| 85 | | 57.5 | ... | 73.5 | 58.0 | | 94.5 | 52.5 | 142 | 165 |
| 84 | | 56.0 | 88.0 | 73.0 | 57.0 | | 94.0 | 52.0 | 140 | 162 |
| 83 | | 54.0 | 87.5 | 72.0 | 56.0 | | 93.0 | 51.0 | 137 | 159 |
| 82 | | 52.5 | ... | 71.5 | 55.0 | | 92.0 | 50.5 | 135 | 156 |
| 81 | | 51.0 | 87.0 | 71.0 | 54.0 | | 91.0 | 50.0 | 133 | 153 |
| 80 | | 49.0 | 86.5 | 70.0 | 53.0 | | 90.5 | 49.5 | 130 | 150 |
| 79 | | 47.5 | ... | 69.5 | 52.0 | | 89.5 | 49.0 | 128 | 147 |
| 78 | | 46.0 | 86.0 | 69.0 | 51.0 | | 88.5 | 48.5 | 126 | 144 |
| 77 | | 44.0 | 85.5 | 68.0 | 50.0 | | 88.0 | 48.0 | 124 | 141 |
| 76 | | 42.5 | ... | 67.5 | 49.0 | | 87.0 | 47.0 | 122 | 139 |
| 75 | 99.5 | 41.0 | 85.0 | 67.0 | 48.5 | | 86.0 | 46.5 | 120 | 137 |
| 74 | 99.0 | 39.0 | ... | 66.0 | 47.5 | | 85.0 | 46.0 | 118 | 135 |
| 73 | 98.5 | 37.5 | 84.5 | 65.5 | 46.5 | | 84.5 | 45.5 | 116 | 132 |
| 72 | 98.0 | 36.0 | 84.0 | 65.0 | 45.5 | | 83.5 | 45.0 | 114 | 130 |
| 71 | 97.5 | 34.5 | ... | 64.0 | 44.5 | 100 | 82.5 | 44.5 | 112 | 127 |
| 70 | 97.0 | 32.5 | 83.5 | 63.5 | 43.5 | 99.5 | 81.5 | 44.0 | 110 | 125 |
| 69 | 96.0 | 31.0 | 83.0 | 62.5 | 42.5 | 99.0 | 81.0 | 43.5 | 109 | 123 |
| 68 | 95.5 | 29.5 | ... | 62.0 | 41.5 | 98.0 | 80.0 | 43.0 | 107 | 121 |
| 67 | 95.0 | 28.0 | 82.5 | 61.5 | 40.5 | 97.5 | 79.0 | 42.5 | 106 | 119 |
| 66 | 94.5 | 26.5 | 82.0 | 60.5 | 39.5 | 97.0 | 78.0 | 42.0 | 104 | 117 |
| 65 | 94.0 | 25.0 | ... | 60.0 | 38.5 | 96.0 | 77.5 | ... | 102 | 116 |
| 64 | 93.5 | 23.5 | 81.5 | 59.5 | 37.5 | 95.5 | 76.5 | 41.5 | 101 | 114 |
| 63 | 93.0 | 22.0 | 81.0 | 58.5 | 36.5 | 95.0 | 75.5 | 41.0 | 99 | 112 |
| 62 | 92.0 | 20.5 | ... | 58.0 | 35.5 | 94.5 | 74.5 | 40.5 | 98 | 110 |
| 61 | 91.5 | 19.0 | 80.5 | 57.0 | 34.5 | 93.5 | 74.0 | 40.0 | 96 | 108 |
| 60 | 91.0 | 17.5 | ... | 56.5 | 33.5 | 93.0 | 73.0 | 39.5 | 95 | 107 |
| 59 | 90.5 | 16.0 | 80.0 | 56.0 | 32.0 | 92.5 | 72.0 | 39.0 | 94 | 106 |
| 58 | 90.0 | 14.5 | 79.5 | 55.0 | 31.0 | 92.0 | ... | 71.0 | 38.5 | 92 |
| 57 | 89.5 | 13.0 | ... | 54.5 | 30.0 | 91.0 | ... | 70.5 | 38.0 | 91 |
| 56 | 89.0 | 11.5 | 79.0 | 54.0 | 29.0 | 90.5 | ... | 69.5 | ... | 90 |
| 55 | 88.0 | 10.0 | 78.5 | 53.0 | 28.0 | 90.0 | ... | 68.5 | 37.5 | 89 |
| 54 | 87.5 | 8.5 | ... | 52.5 | 27.0 | 89.5 | ... | 68.0 | 37.0 | 87 |
| 53 | 87.0 | 7.0 | 78.0 | 51.5 | 26.0 | 89.0 | ... | 67.0 | 36.5 | 86 |
| 52 | 86.5 | 5.5 | 77.5 | 51.0 | 25.0 | 88.0 | ... | 66.0 | 36.0 | 85 |
| 51 | 86.0 | 4.0 | ... | 50.5 | 24.0 | 87.5 | ... | 65.0 | 35.5 | 84 |
| 50 | 85.5 | 2.5 | 77.0 | 49.5 | 23.0 | 87.0 | ... | 64.5 | 35.0 | 83 |
| 50 | 85.5 | 2.5 | 77.0 | 49.5 | 23.0 | 87.0 | ... | 64.5 | 35.0 | 83 |
| 49 | 85.0 | 1.0 | 76.5 | 49.0 | 22.0 | 86.5 | ... | 63.5 | ... | 82 |

Table 13. Comparative Hardness Scales for Unhardened Steel, Soft-Temper Steel, Grey and Malleable Cast Iron, and Nonferrous Alloys

| Rockwell Hardness Number | | | Rockwell Superficial Hardness Number | | | Rockwell Hardness Number | | | Brinell Hardness Number | |
|---|--|---|--|--|--|--|--|--|---|--|
| Rockwell B scale $\frac{1}{16}$ " Ball Penetrator 100-kg Load | Rockwell F scale $\frac{1}{16}$ " Ball Penetrator 60-kg Load | Rockwell G scale $\frac{1}{16}$ " Ball Penetrator 150-kg Load | Rockwell Superficial 15-T scale $\frac{1}{16}$ " Ball Penetrator | Rockwell Superficial 30-T scale $\frac{1}{16}$ " Ball Penetrator | Rockwell Superficial 45-T scale $\frac{1}{16}$ " Ball Penetrator | Rockwell E scale $\frac{1}{8}$ " Ball Penetrator 100-kg Load | Rockwell K scale $\frac{1}{8}$ " Ball Penetrator 150-kg Load | Rockwell A scale "Brile" Penetrator 60-kg Load | Brinell Scale 10-mm Standard Ball 500-kg Load | Brinell Scale 10-mm Standard Ball 3000-kg Load |
| 48 | 84.5 | ... | ... | 48.5 | 20.5 | 85.5 | ... | 62.5 | 34.5 | 81 |
| 47 | 84.0 | ... | 76.0 | 47.5 | 19.5 | 85.0 | ... | 61.5 | 34.0 | 80 |
| 46 | 83.0 | ... | 75.5 | 47.0 | 18.5 | 84.5 | ... | 61.0 | 33.5 | ... |
| 45 | 82.5 | ... | ... | 46.0 | 17.5 | 84.0 | ... | 60.0 | 33.0 | 79 |
| 44 | 82.0 | ... | 75.0 | 45.5 | 16.5 | 83.5 | ... | 59.0 | 32.5 | 78 |
| 43 | 81.5 | ... | 74.5 | 45.0 | 15.5 | 82.5 | ... | 58.0 | 32.0 | 77 |
| 42 | 81.0 | ... | ... | 44.0 | 14.5 | 82.0 | ... | 57.5 | 31.5 | 76 |
| 41 | 80.5 | ... | 74.0 | 43.5 | 13.5 | 81.5 | ... | 56.5 | 31.0 | 75 |
| 40 | 79.5 | ... | 73.5 | 43.0 | 12.5 | 81.0 | ... | 55.5 | ... | ... |
| 39 | 79.0 | ... | ... | 42.0 | 11.0 | 80.0 | ... | 54.5 | 30.5 | 74 |
| 38 | 78.5 | ... | 73.0 | 41.5 | 10.0 | 79.5 | ... | 54.0 | 30.0 | 73 |
| 37 | 78.0 | ... | 72.5 | 40.5 | 9.0 | 79.0 | ... | 53.0 | 29.5 | 72 |
| 36 | 77.5 | ... | ... | 40.0 | 8.0 | 78.5 | 100 | 52.0 | 29.0 | ... |
| 35 | 77.0 | ... | 72.0 | 39.5 | 7.0 | 78.0 | 99.5 | 51.5 | 28.5 | 71 |
| 34 | 76.5 | ... | 71.5 | 38.5 | 6.0 | 77.0 | 99.0 | 50.5 | 28.0 | 70 |
| 33 | 75.5 | ... | ... | 38.0 | 5.0 | 76.5 | ... | 49.5 | ... | 69 |
| 32 | 75.0 | ... | 71.0 | 37.5 | 4.0 | 76.0 | 98.5 | 48.5 | 27.5 | ... |
| 31 | 74.5 | ... | ... | 36.5 | 3.0 | 75.5 | 98.0 | 48.0 | 27.0 | 68 |
| 30 | 74.0 | ... | 70.5 | 36.0 | 2.0 | 75.0 | ... | 47.0 | 26.5 | 67 |
| 29 | 73.5 | ... | 70.0 | 35.5 | 1.0 | 74.0 | 97.5 | 46.0 | 26.0 | ... |
| 28 | 73.0 | ... | ... | 34.5 | ... | 73.5 | 97.0 | 45.0 | 25.5 | 66 |
| 27 | 72.5 | ... | 69.5 | 34.0 | ... | 73.0 | 96.5 | 44.5 | 25.0 | ... |
| 26 | 72.0 | ... | 69.0 | 33.0 | ... | 72.5 | ... | 43.5 | 24.5 | 65 |
| 25 | 71.0 | ... | ... | 32.5 | ... | 72.0 | 96.0 | 42.5 | ... | 64 |
| 24 | 70.5 | ... | 68.5 | 32.0 | ... | 71.0 | 95.5 | 41.5 | 24.0 | ... |
| 23 | 70.0 | ... | 68.0 | 31.0 | ... | 70.5 | ... | 41.0 | 23.5 | 63 |
| 22 | 69.5 | ... | ... | 30.5 | ... | 70.0 | 95.0 | 40.0 | 23.0 | ... |
| 21 | 69.0 | ... | 67.5 | 29.5 | ... | 69.5 | 94.5 | 39.0 | 22.5 | 62 |
| 20 | 68.5 | ... | ... | 29.0 | ... | 68.5 | ... | 38.0 | 22.0 | ... |
| 19 | 68.0 | ... | 67.0 | 28.5 | ... | 68.0 | 94.0 | 37.5 | 21.5 | 61 |
| 18 | 67.0 | ... | 66.5 | 27.5 | ... | 67.5 | 93.5 | 36.5 | ... | ... |
| 17 | 66.5 | ... | ... | 27.0 | ... | 67.0 | 93.0 | 35.5 | 21.0 | 60 |
| 16 | 66.0 | ... | 66.0 | 26.0 | ... | 66.5 | ... | 35.0 | 20.5 | ... |
| 15 | 65.5 | ... | 65.5 | 25.5 | ... | 65.5 | 92.5 | 34.0 | 20.0 | 59 |
| 14 | 65.0 | ... | ... | 25.0 | ... | 65.0 | 92.0 | 33.0 | ... | ... |
| 13 | 64.5 | ... | 65.0 | 24.0 | ... | 64.5 | ... | 32.0 | ... | 58 |
| 12 | 64.0 | ... | 64.5 | 23.5 | ... | 64.0 | 91.5 | 31.5 | ... | ... |
| 11 | 63.5 | ... | ... | 23.0 | ... | 63.5 | 91.0 | 30.5 | ... | ... |
| 10 | 63.0 | ... | 64.0 | 22.0 | ... | 62.5 | 90.5 | 29.5 | ... | 57 |
| 9 | 62.0 | ... | ... | 21.5 | ... | 62.0 | ... | 29.0 | ... | ... |
| 8 | 61.5 | ... | 63.5 | 20.5 | ... | 61.5 | 90.0 | 28.0 | ... | ... |
| 7 | 61.0 | ... | 63.0 | 20.0 | ... | 61.0 | 89.5 | 27.0 | ... | 56 |
| 6 | 60.5 | ... | ... | 19.5 | ... | 60.5 | ... | 26.0 | ... | ... |
| 5 | 60.0 | ... | 62.5 | 18.5 | ... | 60.0 | 89.0 | 25.5 | ... | 55 |
| 4 | 59.5 | ... | 62.0 | 18.0 | ... | 59.0 | 88.5 | 24.5 | ... | ... |
| 3 | 59.0 | ... | ... | 17.0 | ... | 58.5 | 88.0 | 23.5 | ... | ... |
| 2 | 58.0 | ... | 61.5 | 16.5 | ... | 58.0 | ... | 23.0 | ... | 54 |
| 1 | 57.5 | ... | 61.0 | 16.0 | ... | 57.5 | 87.5 | 22.0 | ... | ... |
| 0 | 57.0 | ... | ... | 15.0 | ... | 57.0 | 87.0 | 21.0 | ... | 53 |

Not applicable to annealed metals of high B-scale hardness such as austenitic stainless steels, nickel and high-nickel alloys nor to cold-worked metals of low B-scale hardness such as aluminum and the softer alloys.

(Compiled by Wilson Mechanical Instrument Co.)

Table 14. Weights of Various Metals and Shapes in Pounds per Linear Foot

| Metal | Rounds | Squares | Hexagons | Octagons | Flats | Round Tubing |
|-----------------------------|--------------------|--------------------|--------------------|--------------------|---------------------------|---------------------------------|
| Steel-Carbon & Alloy | $2.673 \times D^2$ | $3.403 \times D^2$ | $2.947 \times D^2$ | $2.819 \times D^2$ | $3.403 \times T \times W$ | $10.680 \times (OD-w) \times w$ |
| Steel, Stainless 300 series | $2.700 \times D^2$ | $3.437 \times D^2$ | $2.977 \times D^2$ | $2.847 \times D^2$ | $3.437 \times T \times W$ | $10.787 \times (OD-w) \times w$ |
| Steel, Stainless 400 series | $2.673 \times D^2$ | $3.403 \times D^2$ | $2.947 \times D^2$ | $2.819 \times D^2$ | $3.403 \times T \times W$ | $10.680 \times (OD-w) \times w$ |
| Aluminum 1100 | $0.925 \times D^2$ | $1.180 \times D^2$ | $1.020 \times D^2$ | $0.976 \times D^2$ | $1.180 \times T \times W$ | $3.700 \times (OD-w) \times w$ |
| Aluminum 2011 | $0.963 \times D^2$ | $1.227 \times D^2$ | $1.062 \times D^2$ | $1.016 \times D^2$ | $1.227 \times T \times W$ | $3.849 \times (OD-w) \times w$ |
| Aluminum 2014 | $0.954 \times D^2$ | $1.214 \times D^2$ | $1.052 \times D^2$ | $1.006 \times D^2$ | $1.214 \times T \times W$ | $3.811 \times (OD-w) \times w$ |
| Aluminum 2017 | $0.954 \times D^2$ | $1.214 \times D^2$ | $1.052 \times D^2$ | $1.006 \times D^2$ | $1.214 \times T \times W$ | $3.811 \times (OD-w) \times w$ |
| Aluminum 2024 | $0.954 \times D^2$ | $1.214 \times D^2$ | $1.052 \times D^2$ | $1.006 \times D^2$ | $1.214 \times T \times W$ | $3.811 \times (OD-w) \times w$ |
| Aluminum 3003 | $0.935 \times D^2$ | $1.190 \times D^2$ | $1.031 \times D^2$ | $0.986 \times D^2$ | $1.190 \times T \times W$ | $3.736 \times (OD-w) \times w$ |
| Aluminum 5005 | $0.925 \times D^2$ | $1.178 \times D^2$ | $1.020 \times D^2$ | $0.976 \times D^2$ | $1.178 \times T \times W$ | $3.697 \times (OD-w) \times w$ |
| Aluminum 5052 | $0.916 \times D^2$ | $1.166 \times D^2$ | $1.010 \times D^2$ | $0.966 \times D^2$ | $1.166 \times T \times W$ | $3.660 \times (OD-w) \times w$ |
| Aluminum 5056 | $0.897 \times D^2$ | $1.142 \times D^2$ | $0.989 \times D^2$ | $0.946 \times D^2$ | $1.142 \times T \times W$ | $3.584 \times (OD-w) \times w$ |
| Aluminum 5083 | $0.907 \times D^2$ | $1.154 \times D^2$ | $1.000 \times D^2$ | $0.956 \times D^2$ | $1.154 \times T \times W$ | $3.623 \times (OD-w) \times w$ |
| Aluminum 5086 | $0.907 \times D^2$ | $1.154 \times D^2$ | $1.000 \times D^2$ | $0.956 \times D^2$ | $1.154 \times T \times W$ | $3.623 \times (OD-w) \times w$ |
| Aluminum 6061 | $0.925 \times D^2$ | $1.178 \times D^2$ | $1.020 \times D^2$ | $0.976 \times D^2$ | $1.178 \times T \times W$ | $3.697 \times (OD-w) \times w$ |
| Aluminum 6063 | $0.916 \times D^2$ | $1.166 \times D^2$ | $1.010 \times D^2$ | $0.966 \times D^2$ | $1.166 \times T \times W$ | $3.660 \times (OD-w) \times w$ |
| Aluminum 7075 | $0.954 \times D^2$ | $1.214 \times D^2$ | $1.052 \times D^2$ | $1.006 \times D^2$ | $1.214 \times T \times W$ | $3.811 \times (OD-w) \times w$ |
| Aluminum 7178 | $0.963 \times D^2$ | $1.227 \times D^2$ | $1.062 \times D^2$ | $1.016 \times D^2$ | $1.227 \times T \times W$ | $3.849 \times (OD-w) \times w$ |
| Beryllium | $0.631 \times D^2$ | $0.803 \times D^2$ | $0.696 \times D^2$ | $0.665 \times D^2$ | $0.803 \times T \times W$ | $2.520 \times (OD-w) \times w$ |
| Brass | $2.897 \times D^2$ | $3.689 \times D^2$ | $3.195 \times D^2$ | $3.056 \times D^2$ | $3.689 \times T \times W$ | $11.577 \times (OD-w) \times w$ |
| Cast Iron | $2.435 \times D^2$ | $3.100 \times D^2$ | $2.685 \times D^2$ | $2.568 \times D^2$ | $3.100 \times T \times W$ | $9.729 \times (OD-w) \times w$ |
| Copper | $3.058 \times D^2$ | $3.893 \times D^2$ | $3.372 \times D^2$ | $3.225 \times D^2$ | $3.893 \times T \times W$ | $12.218 \times (OD-w) \times w$ |
| Gold | $6.591 \times D^2$ | $8.392 \times D^2$ | $7.268 \times D^2$ | $6.950 \times D^2$ | $8.392 \times T \times W$ | $26.337 \times (OD-w) \times w$ |
| Lead | $3.870 \times D^2$ | $4.928 \times D^2$ | $4.268 \times D^2$ | $4.082 \times D^2$ | $4.928 \times T \times W$ | $15.465 \times (OD-w) \times w$ |
| Magnesium | $0.612 \times D^2$ | $0.779 \times D^2$ | $0.675 \times D^2$ | $0.646 \times D^2$ | $0.779 \times T \times W$ | $2.446 \times (OD-w) \times w$ |
| Molybdenum | $3.483 \times D^2$ | $4.434 \times D^2$ | $3.840 \times D^2$ | $3.674 \times D^2$ | $4.434 \times T \times W$ | $13.916 \times (OD-w) \times w$ |
| Monel | $2.897 \times D^2$ | $3.689 \times D^2$ | $3.195 \times D^2$ | $3.056 \times D^2$ | $3.689 \times T \times W$ | $11.577 \times (OD-w) \times w$ |
| Nickel | $3.039 \times D^2$ | $3.869 \times D^2$ | $3.351 \times D^2$ | $3.206 \times D^2$ | $3.869 \times T \times W$ | $12.143 \times (OD-w) \times w$ |
| Silver | $3.579 \times D^2$ | $4.557 \times D^2$ | $3.946 \times D^2$ | $3.775 \times D^2$ | $4.557 \times T \times W$ | $14.301 \times (OD-w) \times w$ |
| Tantalum | $5.667 \times D^2$ | $7.215 \times D^2$ | $6.248 \times D^2$ | $5.977 \times D^2$ | $7.215 \times T \times W$ | $22.642 \times (OD-w) \times w$ |
| Tin | $2.491 \times D^2$ | $3.172 \times D^2$ | $2.747 \times D^2$ | $2.628 \times D^2$ | $3.172 \times T \times W$ | $9.953 \times (OD-w) \times w$ |
| Titanium | $1.537 \times D^2$ | $1.575 \times D^2$ | $1.695 \times D^2$ | $1.621 \times D^2$ | $1.957 \times T \times W$ | $6.141 \times (OD-w) \times w$ |
| Tungsten | $6.580 \times D^2$ | $8.379 \times D^2$ | $7.256 \times D^2$ | $6.941 \times D^2$ | $8.379 \times T \times W$ | $26.294 \times (OD-w) \times w$ |
| Zinc | $2.435 \times D^2$ | $3.100 \times D^2$ | $2.685 \times D^2$ | $2.568 \times D^2$ | $3.100 \times T \times W$ | $9.729 \times (OD-w) \times w$ |
| Zirconium | $2.170 \times D^2$ | $0.763 \times D^2$ | $0.393 \times D^2$ | $0.289 \times D^2$ | $0.763 \times T \times W$ | $8.672 \times (OD-w) \times w$ |

Based on information from Steel and Aluminum Stock List and Reference Book published by Earle M. Jorgensen Co.

D = diameter or Distance across flats, OD = Outside Diameter (0.000), T = Thickness in inches, W = Width in inches, w = wall thickness (0.000)

Table 15. Weight of Round, Square, Hexagonal, and Octagonal Carbon Bar Steel
 Weight in Pounds per Linear foot, from $\frac{1}{16}$ to 3 inch Diameter

| Size or diameter inches | Round | Square | Hexagonal | Octagonal |
|----------------------------|--------|--------|-----------|-----------|
| $\frac{1}{16}$ | 0.010 | 0.013 | 0.011 | 0.016 |
| $\frac{1}{8}$ | 0.042 | 0.053 | 0.046 | 0.044 |
| $\frac{3}{16}$ | 0.094 | 0.119 | 0.104 | 0.099 |
| $\frac{1}{4}$ | 0.167 | 0.212 | 0.183 | 0.176 |
| $\frac{5}{16}$ | 0.261 | 0.333 | 0.288 | 0.276 |
| $\frac{3}{8}$ | 0.376 | 0.478 | 0.414 | 0.397 |
| $\frac{7}{16}$ | 0.511 | 0.651 | 0.564 | 0.540 |
| $\frac{1}{2}$ | 0.667 | 0.85 | 0.736 | 0.705 |
| $\frac{9}{16}$ | 0.845 | 1.076 | 0.932 | 0.892 |
| $\frac{5}{8}$ | 1.043 | 1.328 | 1.150 | 1.101 |
| $1\frac{1}{16}$ | 1.262 | 1.607 | 1.392 | 1.331 |
| $\frac{3}{4}$ | 1.502 | 1.913 | 1.656 | 1.586 |
| $1\frac{3}{16}$ | 1.763 | 2.245 | 1.944 | 1.861 |
| $\frac{7}{8}$ | 2.044 | 2.603 | 2.254 | 2.159 |
| $1\frac{5}{16}$ | 2.347 | 2.989 | 2.588 | 2.478 |
| 1 | 2.670 | 3.401 | 2.944 | 2.819 |
| $1\frac{1}{16}$ | 3.014 | 3.838 | 3.324 | 3.183 |
| $1\frac{1}{8}$ | 3.379 | 4.303 | 3.727 | 3.569 |
| $1\frac{3}{16}$ | 3.766 | 4.795 | 4.152 | 3.976 |
| $1\frac{1}{4}$ | 4.173 | 5.313 | 4.601 | 4.405 |
| $1\frac{5}{16}$ | 4.600 | 5.857 | 5.069 | 4.856 |
| $1\frac{3}{8}$ | 5.049 | 6.428 | 5.567 | 5.331 |
| $1\frac{7}{16}$ | 5.518 | 7.026 | 6.075 | 5.826 |
| $1\frac{1}{2}$ | 6.008 | 7.651 | 6.625 | 6.344 |
| $1\frac{1}{16}$ | 6.520 | 8.301 | 7.182 | 6.883 |
| $1\frac{5}{8}$ | 7.051 | 8.978 | 7.775 | 7.445 |
| $1\frac{11}{16}$ | 7.604 | 9.682 | 8.378 | 8.028 |
| $1\frac{3}{4}$ | 8.178 | 10.413 | 9.018 | 8.633 |
| $1\frac{13}{16}$ | 8.773 | 11.170 | 9.673 | 9.261 |
| $1\frac{1}{8}$ | 9.388 | 11.953 | 10.355 | 9.911 |
| $1\frac{15}{16}$ | 10.024 | 12.763 | 11.053 | 10.574 |
| 2 | 10.682 | 13.601 | 11.778 | 11.276 |
| $2\frac{1}{16}$ | 11.360 | 14.463 | 12.526 | 11.988 |
| $2\frac{1}{8}$ | 12.059 | 15.353 | 13.296 | 12.724 |
| $2\frac{3}{16}$ | 12.778 | 16.27 | 14.085 | 13.478 |
| $2\frac{1}{4}$ | 13.519 | 17.217 | 14.907 | 14.264 |
| $2\frac{5}{16}$ | 14.280 | 18.185 | 15.746 | 15.083 |
| $2\frac{3}{8}$ | 15.068 | 19.178 | 16.609 | 15.893 |
| $2\frac{7}{16}$ | 15.866 | 20.201 | 17.495 | 16.752 |
| $2\frac{1}{2}$ | 16.690 | 21.250 | 18.407 | 17.619 |
| $2\frac{9}{16}$ | 17.534 | 22.326 | 19.342 | 18.505 |
| $2\frac{5}{8}$ | 18.401 | 23.428 | 20.294 | 19.436 |
| $2\frac{11}{16}$ | 19.287 | 24.557 | 21.272 | 20.364 |
| $2\frac{3}{4}$ | 20.195 | 25.713 | 22.268 | 21.301 |
| $2\frac{13}{16}$ | 21.123 | 26.895 | 23.293 | 22.310 |

Table 15. Weight of Round, Square, Hexagonal, and Octagonal Carbon Bar Steel
Weight in Pounds per Linear foot, from $\frac{1}{16}$ to 3 inch Diameter

| Size or diameter inches | Round | Square | Hexagonal | Octagonal |
|----------------------------|--------|--------|-----------|-----------|
| $2\frac{7}{8}$ | 22.072 | 28.103 | 24.336 | 23.302 |
| $2\frac{15}{16}$ | 23.043 | 29.339 | 25.404 | 24.325 |
| 3 | 24.034 | 30.601 | 26.504 | 25.38 |
| $3\frac{1}{16}$ | 25.045 | 31.889 | ... | ... |
| $3\frac{1}{8}$ | 26.078 | 33.204 | ... | ... |
| $3\frac{3}{16}$ | 27.132 | 34.545 | ... | ... |
| $3\frac{1}{4}$ | 28.206 | 35.913 | ... | ... |
| $3\frac{5}{16}$ | 28.301 | 37.308 | ... | ... |
| $3\frac{3}{8}$ | 30.417 | 38.729 | ... | ... |
| $3\frac{7}{16}$ | 31.554 | 40.176 | ... | ... |
| $3\frac{1}{2}$ | 32.712 | 41.651 | ... | ... |
| $3\frac{9}{16}$ | 33.891 | 43.151 | ... | ... |
| $3\frac{5}{8}$ | 35.091 | 44.679 | ... | ... |
| $3\frac{11}{16}$ | 36.311 | 46.233 | ... | ... |
| $3\frac{3}{4}$ | 37.552 | 47.813 | ... | ... |
| $3\frac{13}{16}$ | 38.815 | 49.420 | ... | ... |
| $3\frac{7}{8}$ | 40.098 | 51.054 | ... | ... |
| $3\frac{15}{16}$ | 41.401 | 52.714 | ... | ... |
| 4 | 42.726 | 54.401 | ... | ... |

Table 16. Aluminium Alloy Properties and Designations

| Series Group | Alloying Elements | Comments |
|--------------|-----------------------|--|
| 1 xxx | See notes below | High corrosion resistance; high thermal and electrical conductivity, low mechanical properties and good workability. |
| 2 xxx | Copper | Require solution heat-treatment to obtain optimum properties. In some cases artificial aging can further increase mechanical properties. |
| 3 xxx | Manganese | Generally not heat-treatable. 3003 is used for moderate strength applications requiring good workability. |
| 4 xxx | Silicon | Most alloys in this series are not-heat-treatable. |
| 5 xxx | Magnesium | Good welding characteristics and resistance to corrosion in marine atmospheres. |
| 6 xxx | Magnesium and Silicon | Capable of being heat treated; may be formed in the -T4 temper and then reach full -T6 properties by artificial aging. Good formability and corrosion resistance with medium strength. |
| 7 xxx | Zinc | When coupled with a smaller percentage of magnesium result in heat-treatable alloys of very high strength. Usually other elements such as Copper and Chromium are added in small quantities. |
| 8 xxx | Other Elements | Unused Series (not currently assigned) |
| 9 xxx | | |

1000 series-1, indicates an Al of 99.00% or greater purity. The last two of the four digits indicate to the nearest hundredth the amount of Al above 99.00%

2000-8000 series-The last two of the four digit series have no significance but are used to identify different alloys in the group.

The second digit indicates alloy modification, or special control of impurities. If the second digit is zero, it indicates no special control of impurities, or the original alloy.

Table 17. Typical Thermal Properties of Various Metals

| Material and Alloy Designation ^a | Density, ρ lb/in ³ | Melting Point, °F | | Conductiv- ity, k , Btu/hr-ft-°F | Specific Heat, C , Btu/lb-°F | Coeff. of Expansion, α μin./in.- °F |
|---|--|-------------------|----------|--|--------------------------------------|---|
| | | solidus | liquidus | | | |
| Aluminum Alloys | | | | | | |
| 2011 | 0.102 | 995 | 1190 | 82.5 | 0.23 | 12.8 |
| 2017 | 0.101 | 995 | 1185 | 99.4 | 0.22 | 13.1 |
| 2024 | 0.100 | 995 | 1180 | 109.2 | 0.22 | 12.9 |
| 3003 | 0.099 | 1190 | 1210 | 111 | 0.22 | 12.9 |
| 5052 | 0.097 | 1100 | 1200 | 80 | 0.22 | 13.2 |
| 5086 | 0.096 | 1085 | 1185 | 73 | 0.23 | 13.2 |
| 6061 | 0.098 | 1080 | 1200 | 104 | 0.23 | 13.0 |
| 7075 | 0.101 | 890 | 1180 | 70 | 0.23 | 13.1 |
| Copper-Base Alloys | | | | | | |
| Manganese Bronze | 0.302 | 1590 | 1630 | 61 | 0.09 | 11.8 |
| C11000 (Electrolytic tough pitch) | 0.321 | 1941 | 1981 | 226 | 0.09 | 9.8 |
| C14500 (Free machining Cu) | 0.323 | 1924 | 1967 | 205 | 0.09 | 9.9 |
| C17200, C17300 (Beryllium Cu) | 0.298 | 1590 | 1800 | 62 | 0.10 | 9.9 |
| C18200 (Chromium Cu) | 0.321 | 1958 | 1967 | 187 | 0.09 | 9.8 |
| C18700 (Leaded Cu) | 0.323 | 1750 | 1975 | 218 | 0.09 | 9.8 |
| C22000 (Commercial bronze, 90%) | 0.318 | 1870 | 1910 | 109 | 0.09 | 10.2 |
| C23000 (Red brass, 85%) | 0.316 | 1810 | 1880 | 92 | 0.09 | 10.4 |
| C26000 (Cartridge brass, 70%) | 0.313 | 1680 | 1750 | 70 | 0.09 | 11.1 |
| C27000 (Yellow brass) | 0.306 | 1660 | 1710 | 67 | 0.09 | 11.3 |
| C28000 (Muntz metal, 60%) | 0.303 | 1650 | 1660 | 71 | 0.09 | 11.6 |
| C33000 (Low-leaded brass tube) | 0.310 | 1660 | 1720 | 67 | 0.09 | 11.2 |
| C35300 (High-leaded brass) | 0.306 | 1630 | 1670 | 67 | 0.09 | 11.3 |
| C35600 (Extra-high-leaded brass) | 0.307 | 1630 | 1660 | 67 | 0.09 | 11.4 |
| C36000 (Free machining brass) | 0.307 | 1630 | 1650 | 67 | 0.09 | 11.4 |
| C36500 (Leaded Muntz metal) | 0.304 | 1630 | 1650 | 71 | 0.09 | 11.6 |
| C46400 (Naval brass) | 0.304 | 1630 | 1650 | 67 | 0.09 | 11.8 |
| C51000 (Phosphor bronze, 5% A) | 0.320 | 1750 | 1920 | 40 | 0.09 | 9.9 |
| C54400 (Free cutting phos. bronze) | 0.321 | 1700 | 1830 | 50 | 0.09 | 9.6 |
| C62300 (Aluminum bronze, 9%) | 0.276 | 1905 | 1915 | 31.4 | 0.09 | 9.0 |
| C62400 (Aluminum bronze, 11%) | 0.269 | 1880 | 1900 | 33.9 | 0.09 | 9.2 |
| C63000 (Ni-Al bronze) | 0.274 | 1895 | 1930 | 21.8 | 0.09 | 9.0 |
| Nickel-Silver | 0.314 | 1870 | 2030 | 17 | 0.09 | 9.0 |
| Nickel-Base Alloys | | | | | | |
| Nickel 200, 201, 205 | 0.321 | 2615 | 2635 | 43.3 | 0.11 | 8.5 |
| Hastelloy C-22 | 0.314 | 2475 | 2550 | 7.5 | 0.10 | 6.9 |
| Hastelloy C-276 | 0.321 | 2415 | 2500 | 7.5 | 0.10 | 6.2 |
| Inconel 718 | 0.296 | 2300 | 2437 | 6.5 | 0.10 | 7.2 |
| Monel | 0.305 | 2370 | 2460 | 10 | 0.10 | 8.7 |
| Monel 400 | 0.319 | 2370 | 2460 | 12.6 | 0.10 | 7.7 |
| Monel K500 | 0.306 | 2400 | 2460 | 10.1 | 0.10 | 7.6 |
| Monel R405 | 0.319 | 2370 | 2460 | 10.1 | 0.10 | 7.6 |

Table 17. Typical Thermal Properties of Various Metals

| Material and Alloy Designation ^a | Density, ρ lb/in. ³ | Melting Point, °F | | Conductiv- ity, k , Btu/hr-ft-°F | Specific Heat, C , Btu/lb°F | Coeff. of Expansion, α μin./in.- °F |
|---|---|---|----------|--|-------------------------------------|---|
| | | solidus | liquidus | | | |
| Stainless Steels | | | | | | |
| S30100 | 0.290 | 2550 | 2590 | 9.4 | 0.12 | 9.4 |
| S30200, S30300, S30323 | 0.290 | 2550 | 2590 | 9.4 | 0.12 | 9.6 |
| S30215 | 0.290 | 2500 | 2550 | 9.2 | 0.12 | 9.0 |
| S30400, S30500 | 0.290 | 2550 | 2650 | 9.4 | 0.12 | 9.6 |
| S30430 | 0.290 | 2550 | 2650 | 6.5 | 0.12 | 9.6 |
| S30800 | 0.290 | 2550 | 2650 | 8.8 | 0.12 | 9.6 |
| S30900, S30908 | 0.290 | 2550 | 2650 | 9.0 | 0.12 | 8.3 |
| S31000, S31008 | 0.290 | 2550 | 2650 | 8.2 | 0.12 | 8.8 |
| S31600, S31700 | 0.290 | 2500 | 2550 | 9.4 | 0.12 | 8.8 |
| S31703 | 0.290 | 2500 | 2550 | 8.3 | 0.12 | 9.2 |
| S32100 | 0.290 | 2550 | 2600 | 9.3 | 0.12 | 9.2 |
| S34700 | 0.290 | 2550 | 2650 | 9.3 | 0.12 | 9.2 |
| S34800 | 0.290 | 2550 | 2650 | 9.3 | 0.12 | 9.3 |
| S38400 | 0.290 | 2550 | 2650 | 9.4 | 0.12 | 9.6 |
| S40300, S41000, S41600, S41623 | 0.280 | 2700 | 2790 | 14.4 | 0.11 | 5.5 |
| S40500 | 0.280 | 2700 | 2790 | 15.6 | 0.12 | 6.0 |
| S41400 | 0.280 | 2600 | 2700 | 14.4 | 0.11 | 5.8 |
| S42000, S42020 | 0.280 | 2650 | 2750 | 14.4 | 0.11 | 5.7 |
| S42200 | 0.280 | 2675 | 2700 | 13.8 | 0.11 | 6.2 |
| S42900 | 0.280 | 2650 | 2750 | 14.8 | 0.11 | 5.7 |
| S43000, S43020, S43023 | 0.280 | 2600 | 2750 | 15.1 | 0.11 | 5.8 |
| S43600 | 0.280 | 2600 | 2750 | 13.8 | 0.11 | 5.2 |
| S44002, S44004 | 0.280 | 2500 | 2700 | 14.0 | 0.11 | 5.7 |
| S44003 | 0.280 | 2500 | 2750 | 14.0 | 0.11 | 5.6 |
| S44600 | 0.270 | 2600 | 2750 | 12.1 | 0.12 | 5.8 |
| S50100, S50200 | 0.280 | 2700 | 2800 | 21.2 | 0.11 | 6.2 |
| Cast Iron and Steel | | | | | | |
| Malleable Iron, A220 (50005, 60004, 80002) | 0.265 | | | 29.5 | 0.12 | 7.5 |
| Grey Cast Iron | 0.25 | liquidus approxi- mately, 2100 to 2200, depending on composition | | 28.0 | 0.25 | 5.8 |
| Ductile Iron, A536 (120-90-02) | 0.25 | | | | 0.16 | 5.9-6.2 |
| Ductile Iron, A536 (100-70-03) | 0.25 | | | 20.0 | 0.16 | 5.9-6.2 |
| Ductile Iron, A536 (80-55-06) | 0.25 | | | 18.0 | 0.15 | 5.9-6.2 |
| Ductile Iron, A536 (65-45-120) | 0.25 | | | 20.8 | 0.15 | 5.9-6.2 |
| Ductile Iron, A536 (60-40-18) | 0.25 | | | | 0.12 | 5.9-6.2 |
| Cast Steel, 3%C | 0.25 | liquidus, 2640 | | 28.0 | 0.12 | 7.0 |
| Titanium Alloys | | | | | | |
| Commercially Pure | 0.163 | 3000 | 3040 | 9.0 | 0.12 | 5.1 |
| Ti-5Al-2.5Sn | 0.162 | 2820 | 3000 | 4.5 | 0.13 | 5.3 |
| Ti-8Mn | 0.171 | 2730 | 2970 | 6.3 | 0.19 | 6.0 |

^a Alloy designations correspond to the Aluminum Association numbers for aluminum alloys and to the unified numbering system (UNS) for copper and stainless steel alloys. A220 and A536 are ASTM specified irons.

Table 18. Characteristics of Important Plastics Families

| | |
|--|--|
| ABS (acrylonitrile-butadiene-styrene) | Rigid, low-cost thermoplastic, easily machined and thermo-formed. |
| Acetal | Engineering thermoplastic with good strength, wear resistance, and dimensional stability. More dimensionally stable than nylon under wet and humid conditions. |
| Acrylic | Clear, transparent, strong, break-resistant thermoplastic with excellent chemical resistance and weatherability. |
| CPVC (chlorinated PVC) | Thermoplastic with properties similar to PVC, but operates to a 40-60°F higher temperature. |
| Fiberglass | Thermosetting composite with high strength-to-weight ratio, excellent dielectric properties, and unaffected by corrosion. |
| Nylon | Thermoplastic with excellent impact resistance, ideal for wear applications such as bearings and gears, self-lubricating under some circumstances. |
| PEEK (polyetheretherketone) | Engineering thermoplastic, excellent temperature resistance, suitable for continuous use above 500°F, excellent flexural and tensile properties. |
| PET (polyethylene-terephthalate) | Dimensionally stable thermoplastic with superior machining characteristics compared to acetal. |
| Phenolic | Thermosetting family of plastics with minimal thermal expansion, high compressive strength, excellent wear and abrasion resistance, and a low coefficient of friction. Used for bearing applications and molded parts. |
| Polycarbonate | Transparent tough thermoplastic with high impact strength, excellent chemical resistance and electrical properties, and good dimensional stability. |
| Polypropylene | Good chemical resistance combined with low moisture absorption and excellent electrical properties, retains strength up to 250°F. |
| Polysulfone | Durable thermoplastic, good electrical properties, operates at temperatures in excess of 300°F. |
| Polyurethane | Thermoplastic, excellent impact and abrasion resistance, resists sunlight and weathering. |
| PTFE (polytetrafluoroethylene) | Thermoplastic, low coefficient of friction, withstands up to 500°F, inert to chemicals and solvents, self-lubricating with a low thermal-expansion rate. |
| PVC (polyvinyl chloride) | Thermoplastic, resists corrosive solutions and gases both acid and alkaline, good stiffness. |
| PVDF (polyvinylidene-fluoride) | Thermoplastic, outstanding chemical resistance, excellent substitute for PVC or polypropylene. Good mechanical strength and dielectric properties. |

Table 19. Working With Plastics

| Properties | Comments |
|-----------------------|--|
| Thermal expansion | 10 times higher than metals; more heat generated. Adequate tool clearance must be provided to minimize heating. Heat must be removed by air blast or liquid coolant |
| Elasticity | Modulus is 10-60 times smaller than for metals; this resilience permits much greater deflection. Reduce chatter by close chucking and follow rests. Drilled or tapped holes may end up tapered or of smaller diameter than the tool. |
| Support | Must be firm to prevent distortion. Sharp tools are essential to keep cutting forces to a minimum. |
| Safety | Requires dust control, adequate ventilation, safety guards and eye protection. |
| Work | |
| Cutting Off | Speed 500-800 ft/min. Use tools with greater front and side clearance than are needed for metal. Cutting speeds: about half those used for turning operations. |
| Drilling | Chip flow in drilling is poor; the rake angles are insufficient and cutting speeds vary from the periphery of the drill, imposing severe loading on the workpiece. Use drills of high speed steel or premium high speed steel (T15, M33, or M41-M47) with low helix angles and wide, highly polished flutes. Point angles: 70-120; for rigid polyvinyl chloride and acrylic use 120. Clearance angles: 9-15; for acrylic material use 12-20. |
| Milling | Generally use High Speed Tools (M2, M3, M7, or T15). Carbide C2 is recommended for glass-reinforced nylon, silicone, polyimide, and alloy. Speeds: 800-1400 ft/min for peripheral end milling of many thermoplastics; 400-800 ft/min. for many thermosets. However slower speeds are generally used for other milling operations: 300-500 ft/min. for some thermoplastics; 150-300 ft/min. for some thermosets. |
| Sawing | See Feeds and Speeds section |
| Tapping and Threading | Taps should be M10, M7, or M1, molybdenum high-speed steel, with finish-ground and polished flutes. Two flute taps are recommended for holes up to 0.125 in. diameter. Speed: 50 ft/min. for through-holes in thin cast, molded or extruded thermoplastics and thermosets; 25 ft/min. for filled materials. Reduce speeds for deep or blind holes, and when the percentage of thread is 65-75%. |
| Turning | Use high speed steel and carbide tools. Cutting speeds: 200-500 ft/min. Box tools are good for long, thin parts. |

STANDARDS FOR DRAWINGS**Shop Prints, Reading and Interpreting**

Table 1. American National Standard for Engineering Drawings
ANSI/ASME Y14.2M-1992, R2003

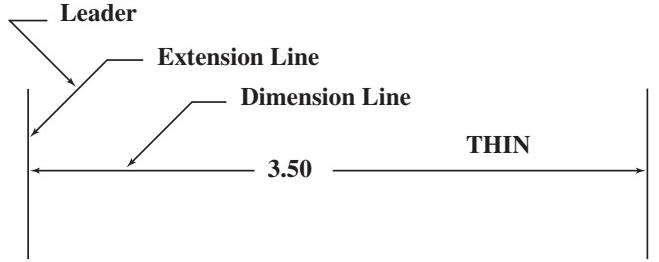
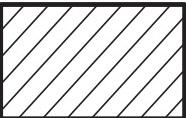
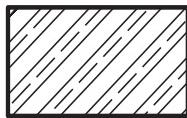
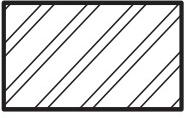
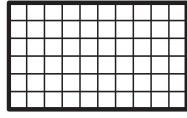
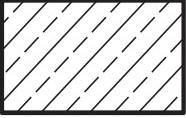
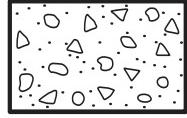
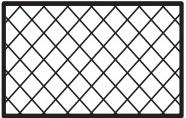
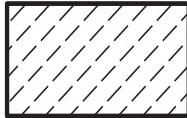
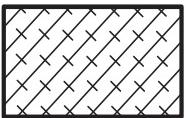
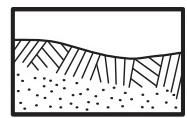
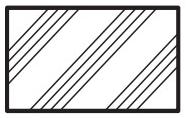
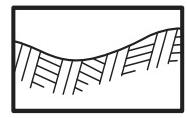
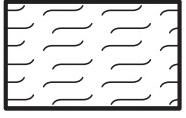
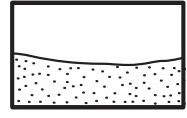
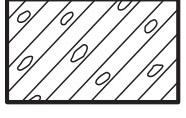
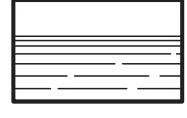
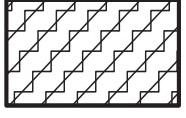
| | |
|--|---|
| Visible Line | THICK |
| Hidden Line | THIN |
| Section Line | THIN |
| Center Line | THIN |
| Symmetry Line | THIN |
| Dimension Line Extension Line And Leader |  <p>Leader Extension Line Dimension Line 3.50 THIN</p> |
| Cutting-Plane Line or Viewing-Plane Line | THICK |
| Break Line |  <p>THICK Short Breaks THIN Long Breaks</p> |
| Phantom Line | THIN |
| Stitch Line | THIN |
| Chain Line | THICK |

Table 2. American National Standard Symbols for Section Lining
ANSI Y14.2M-1979, R1987^a

| | | | |
|---|---|---|--|
|  | Cast and Malleable iron (Also for general use of all materials) |  | Titanium and refractory material |
|  | Steel |  | Electric windings, electro magnets, resistance, etc. |
|  | Bronze, brass, copper, and compositions |  | Concrete |
|  | White metal, zinc, lead, babbitt, and alloys |  | Marble, slate, glass, porcelain, etc. |
|  | Magnesium, aluminum, and aluminum alloys |  | Earth |
|  | Rubber, plastic electrical insulation |  | Rock |
|  | Cork, felt, fabric, leather, fiber |  | Sand |
|  | Sound insulation |  | Water and other liquids |
|  | Thermal insulation |  | Wood-across grain Wood-with grain |

^aThis table has been removed from the current version of standard and is retained here for reference.

Table 3. Comparison of ANSI and ISO Geometric Symbols ASME Y14.5M-1994, R2004

| Symbol for | ANSI Y14.5M | ISO | Symbol for | ANSI Y14.5 | ISO | Symbol for | ANSI Y14.5M | ISO |
|--------------------------|-------------|------|-------------------------------|------------|------|----------------------------|-------------|------------|
| Straightness | | | Circular Runout ^a | | | Feature Control Frame | | |
| Flatness | | | Total Runout ^a | | | Datum Feature ^a | | OR |
| Circularity | | | At Maximum Material Condition | | | All Around - Profile | | (proposed) |
| Cylindricity | | | At Least Material Condition | | | Conical Taper | | |
| Profile of a Line | | | Regardless of Feature Size | NONE | NONE | Slope | | |
| Profile of a Surface | | | Projected Tolerance Zone | | | Counterbore/Spotface | | (proposed) |
| Angularity | | | Diameter | | | Countersink | | (proposed) |
| Perpendicularity | | | Basic Dimension | | | Depth/Deep | | (proposed) |
| Parallelism | | | Reference Dimension | (50) | (50) | Square (Shape) | | |
| Position | | | Datum Target | | | Dimension Not to Scale | | |
| Concentricity/Coaxiality | | | Target Point | | | Number of Times/Places | 8X | 8X |
| Symmetry | | | Dimension Origin | | | Arc Length | | |
| Radius | R | R | Spherical Radius | SR | SR | Spherical Diameter | | |
| Between ^a | | None | Controlled Radius | CR | None | Statistical Tolerance | | None |

^a Arrowheads may be filled in.

Table 4. American National Standard Symbols for Datum Referencing in Engineering Drawing ASME Y14.5M-1994, R2004

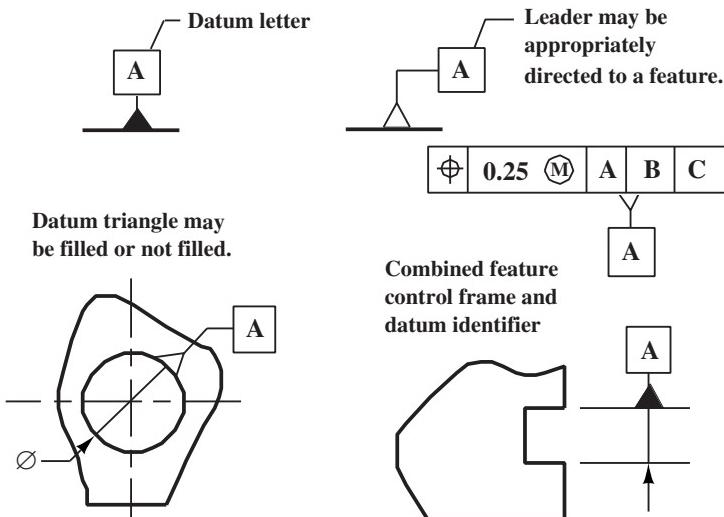


Fig. 2. Datum Feature Symbol

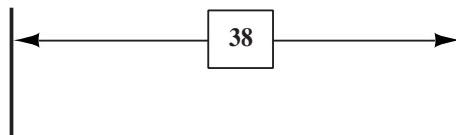


Fig. 3. Basic Dimensions

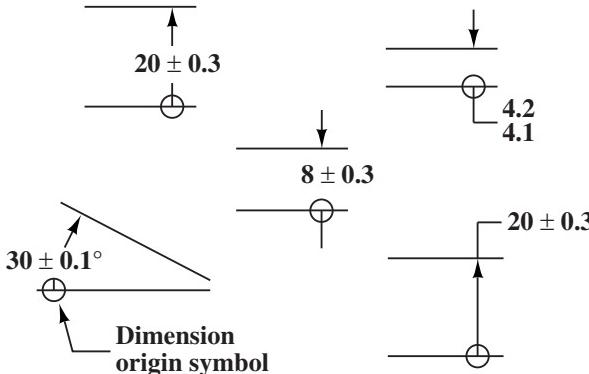


Fig. 4. Dimension Origin Symbol

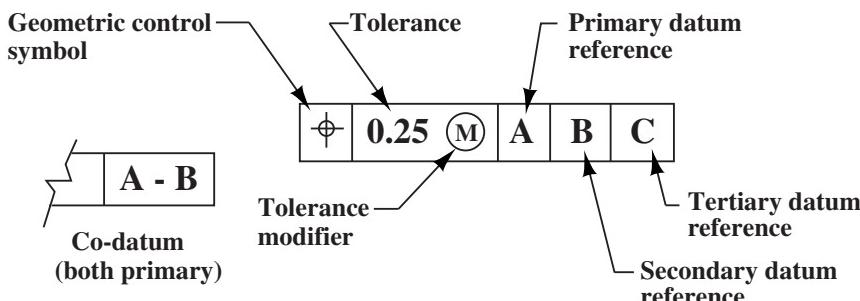


Fig. 5. Feature Control Frame and Datum Order of Precedence

Table 4. (Continued) American National Standard Symbols for Datum Referencing in Engineering Drawing ASME Y14.5M-1994, R2004

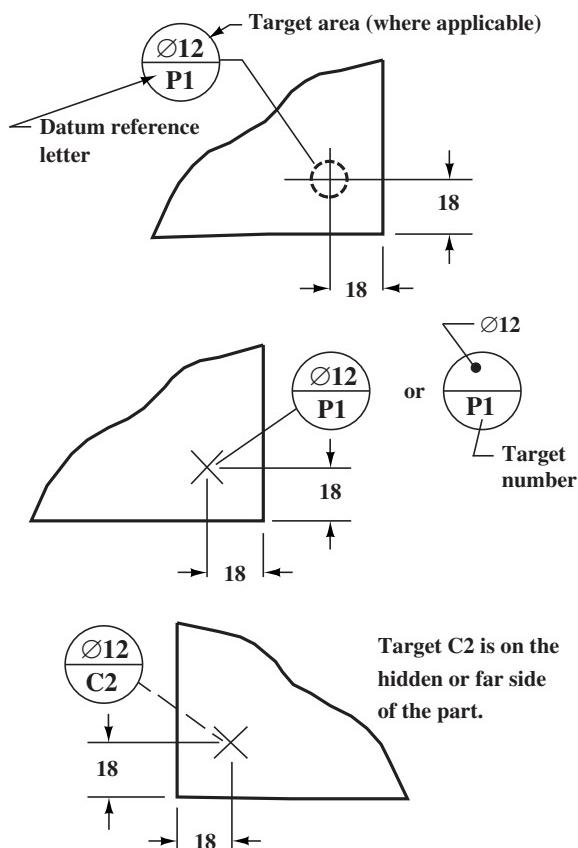


Fig. 6. Datum Target Symbols.

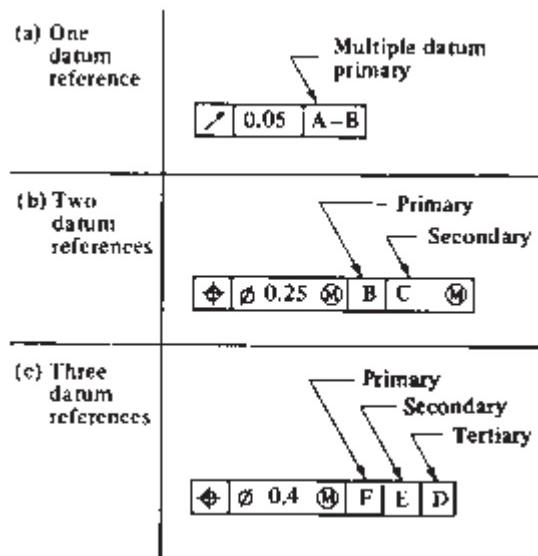


Fig. 7. Order of Precedence of Datum References

Table 4. (Continued) American National Standard Symbols for Datum Referencing in Engineering Drawing ASME Y14.5M-1994, R2004

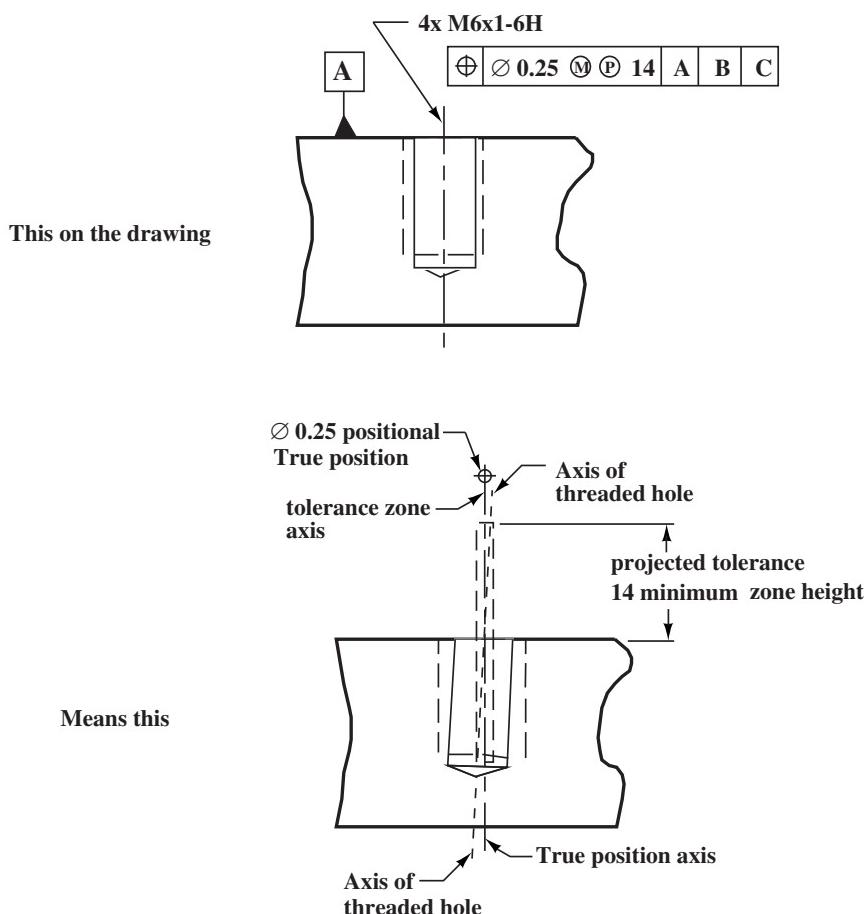


Fig. 8. Projected Tolerance Zone Application.

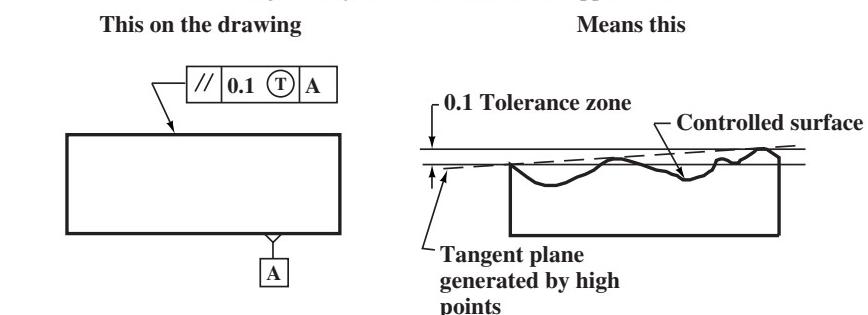


Fig. 9. Tangent Plane Modifier.

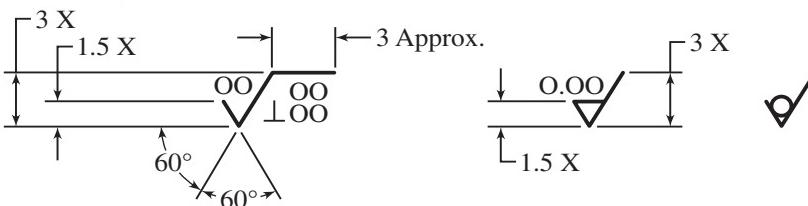
| (F) | (M) | (L) | (T) | (P) | (ST) |
|------------|-----|-----|---------------|--------------------------|-----------------------|
| Free State | MMC | LMC | Tangent Plane | Projected Tolerance Zone | Statistical Tolerance |

Fig. 10. Tolerance Modifiers.

SURFACE TEXTURE

Surface Texture Symbols.—The symbol used to designate control of surface irregularities is shown in Fig. 1a. Where surface texture values other than roughness average are specified, the symbol must be drawn with the horizontal extension as shown in Fig. 1e.

Table 1. Surface Texture Symbols and Construction

| Symbol | Meaning |
|--|--|
|  Fig. 1a. | Basic Surface Texture Symbol. Surface may be produced by any method except when the bar or circle (Fig. 1b or 1d) is specified. |
|  Fig. 1b. | Material Removal By Machining Is Required. The horizontal bar indicates that material removal by machining is required to produce the surface and that material must be provided for that purpose. |
| 3.5  Fig. 1c. | Material Removal Allowance. The number indicates the amount of stock to be removed by machining in millimeters (or inches). Tolerances may be added to the basic value shown or in a general note. |
|  Fig. 1d. | Material Removal Prohibited. The circle in the vee indicates that the surface must be produced by processes such as casting, forging, hot finishing, cold finishing, die casting, powder metallurgy or injection molding without subsequent removal of material. |
|  Fig. 1e. | Surface Texture Symbol. To be used when any surface characteristics are specified above the horizontal line or the right of the symbol. Surface may be produced by any method except when the bar or circle (Fig. 1b and 1d) is specified. |
|  Letter Height = X | |

Use of Surface Texture Symbols: When required from a functional standpoint, the desired surface characteristics should be specified. Where no surface texture control is specified, the surface produced by normal manufacturing methods is satisfactory provided it is within the limits of size (and form) specified in accordance with ANSI/ASME Y14.5M-1994, Dimensioning and Tolerancing. This is not viewed as good practice; there should always be some maximum value, either specifically or by default (for example, in the manner of the note shown in Fig. 2).

Material Removal Required or Prohibited: The surface texture symbol is modified when necessary to require or prohibit removal of material. When it is necessary to indicate that a surface must be produced by removal of material by machining, apply the symbol shown in Fig. 1b. When required, the amount of material to be removed is specified as shown in Fig. 1c, in millimeters for metric drawings and in inches for nonmetric drawings. Tolerance for material removal may be added to the basic value shown or specified in a general note. When it is necessary to indicate that a surface must be produced without material removal, use the machining prohibited symbol as shown in Fig. 1d.

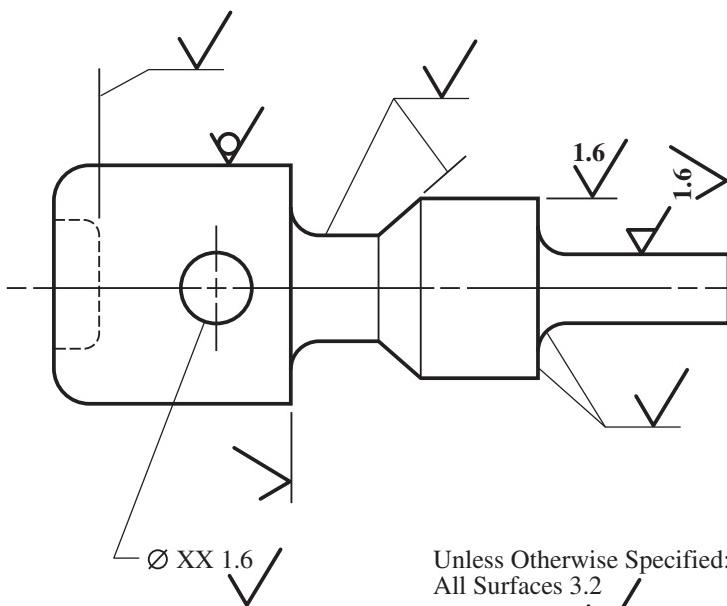


Fig. 2. Application of Surface Texture Symbols

Proportions of Surface Texture Symbols: The recommended proportions for drawing the surface texture symbol are shown in Fig. 1f. The letter height and line width should be the same as that for dimensions and dimension lines.

Applying Surface Texture Symbols.— The point of the symbol should be on a line representing the surface, an extension line of the surface, or to a leader line directed to the surface. The symbol may be specified following a diameter dimension. The long leg (and extension) shall be to the right as the drawing is read. For parts requiring extensive and uniform surface roughness control, a general note may be added to the drawing which applies to each surface texture symbol specified without values as shown in Fig. 2.

When the symbol is used with a dimension it affects the entire surface defined by the dimension. Areas of transition, such as chamfers and fillets, shall conform with the roughest adjacent finished area unless otherwise indicated.

Surface texture values, unless otherwise specified, apply to the complete surface. Drawings or specifications for plated or coated parts shall indicate whether the surface texture values apply before plating, after plating, or both before and after plating.

Include in the symbol only those values required to specify and verify the required texture characteristics. Values should be in metric units for metric drawings and nonmetric units for nonmetric drawings.

Roughness and waviness measurements, unless otherwise specified, apply in the direction that gives the maximum reading; generally across the lay.

Cutoff or Roughness Sampling Length: Standard values are listed in Table 2. When no value is specified, the value 0.8 mm (0.030 in.) applies.

Table 2. Standard Roughness Sampling Length (Cutoff) Values

| mm | in. | mm | in. |
|------|-------|------|-----|
| 0.08 | 0.003 | 2.5 | 0.1 |
| 0.25 | 0.010 | 8.0 | 0.3 |
| 0.80 | 0.030 | 25.0 | 1.0 |

Roughness Average (R_a): The preferred series of specified roughness average values is given in Table 3.

Table 3. Preferred Series Roughness Average Values (R_a)

| $\mu\text{ m}$ | $\mu\text{ in}$ | $\mu\text{ m}$ | $\mu\text{ in}$ |
|--------------------|-----------------|-------------------|-------------------|
| 0.012 | 0.5 | 1.25 | 50 |
| 0.025 ^a | 1 ^a | 1.60 ^a | 63 ^a |
| 0.050 ^a | 2 ^a | 2.0 | 80 |
| 0.075 ^a | 3 | 2.5 | 100 |
| 0.10 ^a | 4 ^a | 3.2 ^a | 125 ^a |
| 0.125 | 5 | 4.0 | 160 |
| 0.15 | 6 | 5.0 | 200 |
| 0.20 ^a | 8 ^a | 6.3 ^a | 250 ^a |
| 0.25 | 10 | 8.0 | 320 |
| 0.32 | 13 | 10.0 | 400 |
| 0.40 ^a | 16 ^a | 12.5 ^a | 500 ^a |
| 0.50 | 20 | 15 | 600 |
| 0.63 | 25 | 20 | 800 |
| 0.80 ^a | 32 ^a | 25 ^a | 1000 ^a |
| 1.00 | 40 | ... | ... |

^a Recommended

Waviness Height: The preferred series of maximum waviness height values is listed in Table 4. Waviness is not currently shown in ISO Standards. It is included here to follow present industry practice in the United States.

Table 4. Preferred Series Maximum Waviness Height Values

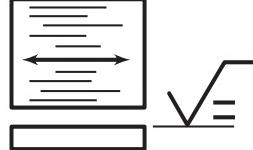
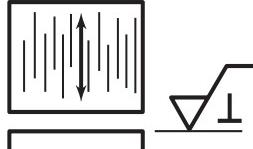
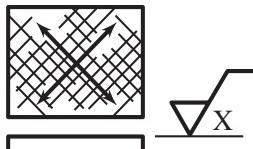
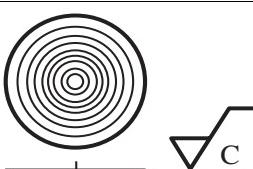
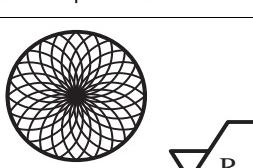
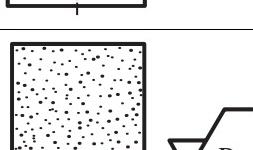
| mm | in. | mm | in. | mm | in. |
|---------|---------|-------|--------|------|-------|
| 0.00002 | 0.00002 | 0.008 | 0.0003 | 0.12 | 0.005 |
| 0.00003 | 0.00003 | 0.012 | 0.0005 | 0.20 | 0.008 |
| 0.00005 | 0.00005 | 0.020 | 0.0008 | 0.25 | 0.010 |
| 0.00008 | 0.00008 | 0.025 | 0.001 | 0.38 | 0.015 |
| 0.0001 | 0.0001 | 0.05 | 0.002 | 0.50 | 0.020 |
| 0.0002 | 0.0002 | 0.08 | 0.003 | 0.80 | 0.030 |

Lay: Symbols for designating the direction of lay are shown and interpreted in Table 5.

Metric Dimensions on Drawings: The length units of the metric system that are most generally used in connection with any work relating to mechanical engineering are the meter (39.37 inches) and the millimeter (0.03937 inch). One meter equals 1000 millimeters. On mechanical drawings, all dimensions are generally given in millimeters, no matter how large the dimensions may be. In fact, dimensions of such machines as locomotives and large electrical apparatus are given exclusively in millimeters. This practice is adopted to avoid mistakes due to misplacing decimal points, or misreading dimensions when other units are used as well. When dimensions are given in millimeters, many of them can be given without resorting to decimal points, as a millimeter is only a little more than $\frac{1}{32}$ inch. Only dimensions of precision need be given in decimals of a millimeter; such dimensions are generally given in hundredths of a millimeter—for example, 0.02 millimeter, which is equal to 0.0008 inch. As 0.01 millimeter is equal to 0.0004 inch, dimensions are seldom given with greater accuracy than to hundredths of a millimeter.

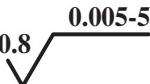
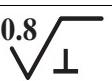
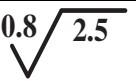
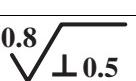
Scales of Metric Drawings: Drawings made to the metric system are not made to scales of $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc., as with drawings made to the English system. If the object cannot be drawn full size, it may be drawn $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{50}$, $\frac{1}{100}$, $\frac{1}{200}$, $\frac{1}{500}$, or $\frac{1}{1000}$ size. If the object is too small and has to be drawn larger, it is drawn 2, 5, or 10 times its actual size.

Table 5. Lay Symbols

| Lay Symbol | Meaning | Example Showing Direction of Tool Marks |
|------------|--|--|
| = | Lay approximately parallel to the line representing the surface to which the symbol is applied. |  |
| ⊥ | Lay approximately perpendicular to the line representing the surface to which the symbol is applied. |  |
| X | Lay angular in both directions to line representing the surface to which the symbol is applied. |  |
| M | Lay multidirectional |  |
| C | Lay approximately circular relative to the center of the surface to which the symbol is applied. |  |
| R | Lay approximately radial relative to the center of the surface to which the symbol is applied. |  |
| P | Lay particulate, non-directional, or protuberant |  |

Example Designations.— Table 6 illustrates examples of designations of roughness, waviness, and lay by insertion of values in appropriate positions relative to the symbol.

Table 6. Application of Surface Texture Values to Symbol

| | | | |
|---|---|---|---|
|  | Roughness average rating is placed at the left of the long leg. The specification of only one rating shall indicate the maximum value and any lesser value shall be acceptable. Specify in micrometers (microinch). |  | Material removal by machining is required to produce the surface. The basic amount of stock provided for material removal is specified at the left of the short leg of the symbol. Specify in millimeters (inch). |
|  | The specification of maximum and minimum roughness average values indicates permissible range of roughness. Specify in micrometers (microinch). |  | Removal of material is prohibited. |
|  | Maximum waviness height rating is the first rating place above the horizontal extension. Any lesser rating shall be acceptable. Specify in millimeters (inch). |  | Lay designation is indicated by the lay symbol placed at the right of the long leg. |
| | Maximum waviness spacing rating is the second rating placed above the horizontal extension and to the right of the waviness height rating. Any lesser rating shall be acceptable. Specify in millimeters (inch). |  | Roughness sampling length or cutoff rating is placed below the horizontal extension. When no value is shown, 0.80 mm (0.030 inch) applies. Specify in millimeters (inch). |
| | |  | Where required maximum roughness spacing shall be placed at the right of the lay symbol. Any lesser rating shall be acceptable. Specify in millimeters (inch). |

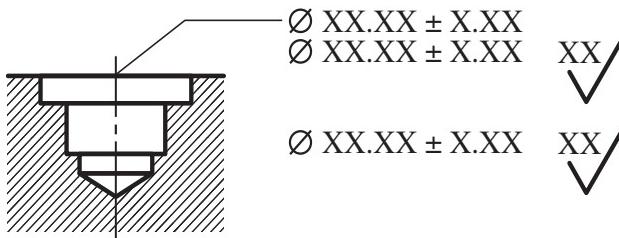
Examples of Special Designations

Fig. 3a.

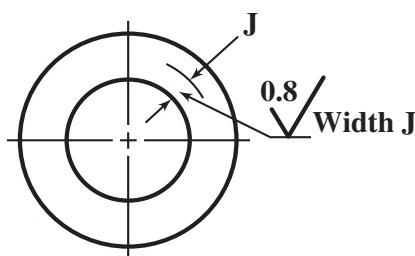
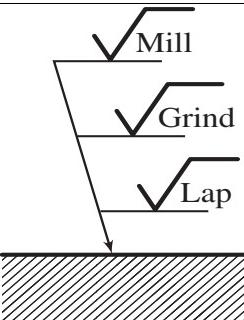


Fig. 3c.

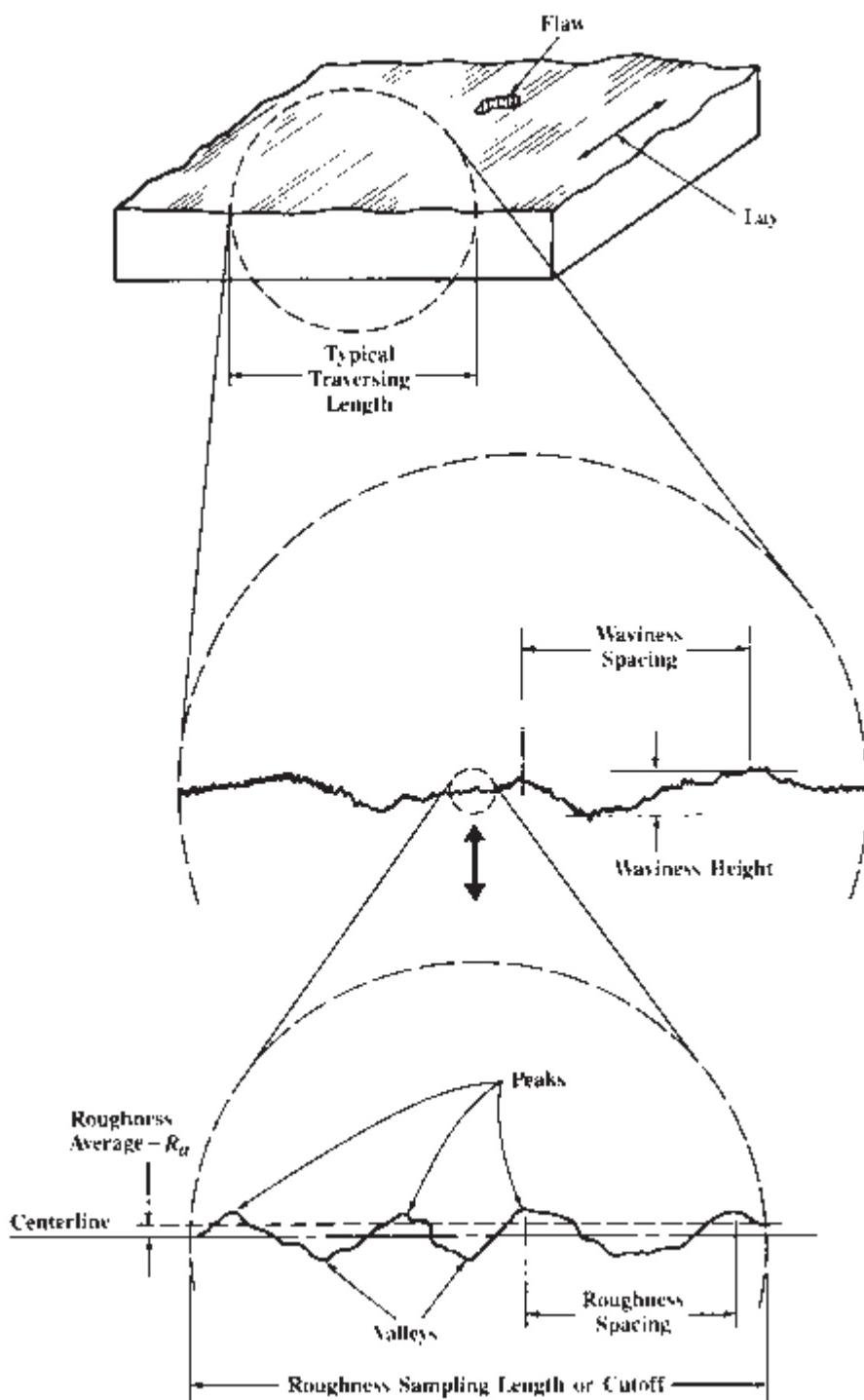
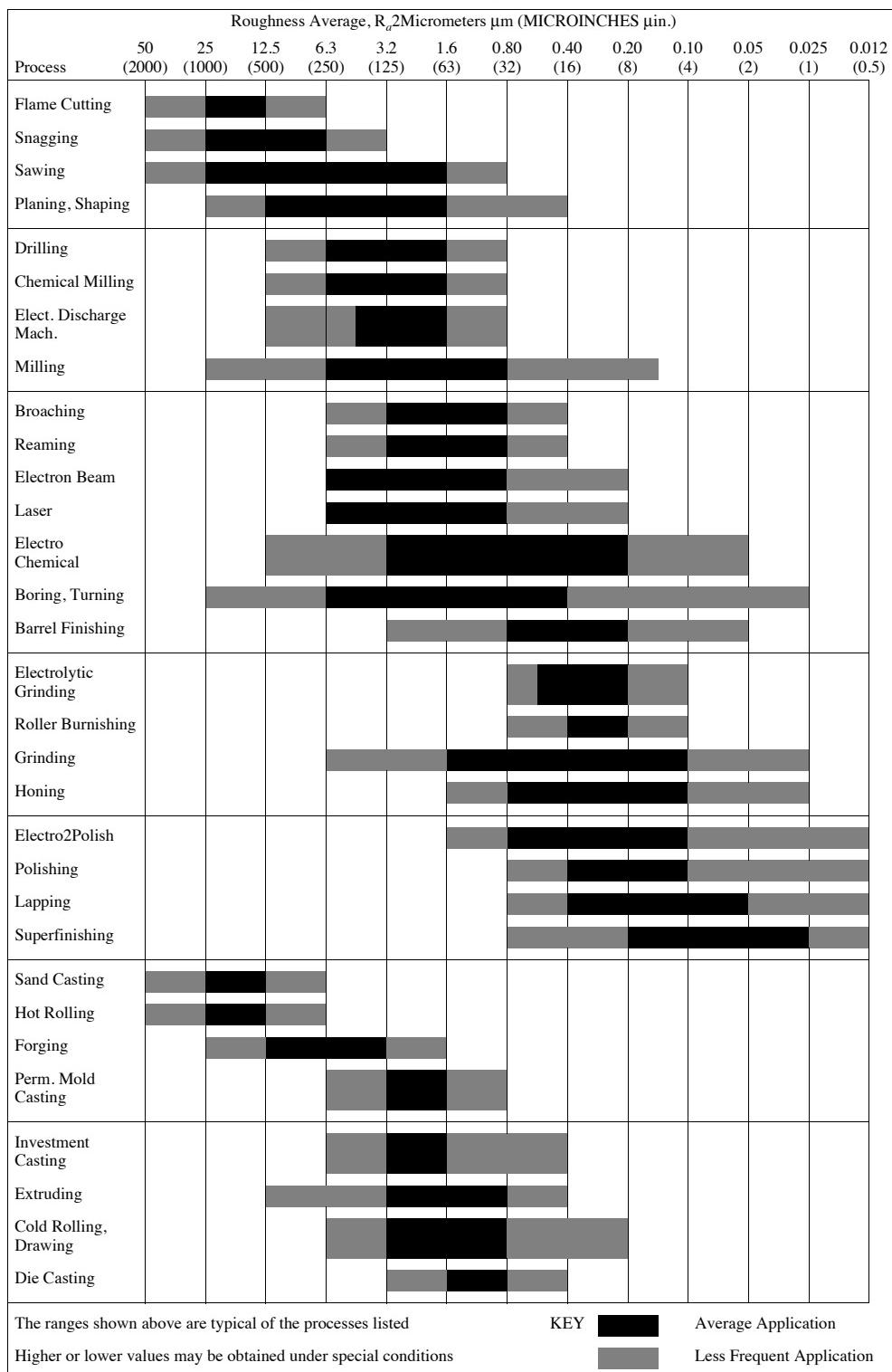


Fig. 1. Pictorial Display of Surface Characteristics

Table 7. Surface Roughness Produced by Common Production Methods

ALLOWANCES AND TOLERANCES

ANSI Standard Limits and Fits (ANSI B4.1-1967, R2004).— This American National Standard for Preferred Limits and Fits for Cylindrical Parts presents definitions of terms applying to fits between plain (non-threaded) cylindrical parts and makes recommendations on preferred sizes, allowances, tolerances, and fits for use wherever they are applicable. This standard is in accord with the recommendations of American-British-Canadian (ABC) conferences for diameters of up to 20 inches. They should have application for a wide range of products.

Preferred Basic Sizes.— In specifying fits, the basic size of mating parts may be chosen from the decimal series or the fractional series in the following Table 1.

Table 1. Preferred Basic Sizes

| Decimal | | | Fractional | | | | | |
|---------|------|-------|-----------------|----------|----------------|--------|-----------------|---------|
| 0.010 | 2.00 | 8.50 | $\frac{1}{64}$ | 0.015625 | $2\frac{1}{4}$ | 2.2500 | $9\frac{1}{2}$ | 9.5000 |
| 0.012 | 2.20 | 9.00 | $\frac{1}{32}$ | 0.03125 | $2\frac{1}{2}$ | 2.5000 | 10 | 10.0000 |
| 0.016 | 2.40 | 9.50 | $\frac{1}{16}$ | 0.0625 | $2\frac{3}{4}$ | 2.7500 | $10\frac{1}{2}$ | 10.5000 |
| 0.020 | 2.60 | 10.00 | $\frac{3}{32}$ | 0.09375 | 3 | 3.0000 | 11 | 11.0000 |
| 0.025 | 2.80 | 10.50 | $\frac{1}{8}$ | 0.1250 | $3\frac{1}{4}$ | 3.2500 | $11\frac{1}{2}$ | 11.5000 |
| 0.032 | 3.00 | 11.00 | $\frac{5}{32}$ | 0.15625 | $3\frac{1}{2}$ | 3.5000 | 12 | 12.0000 |
| 0.040 | 3.20 | 11.50 | $\frac{3}{16}$ | 0.1875 | $3\frac{3}{4}$ | 3.7500 | $12\frac{1}{2}$ | 12.5000 |
| 0.05 | 3.40 | 12.00 | $\frac{1}{4}$ | 0.2500 | 4 | 4.0000 | 13 | 13.0000 |
| 0.06 | 3.60 | 12.50 | $\frac{5}{16}$ | 0.3125 | $4\frac{1}{4}$ | 4.2500 | $13\frac{1}{2}$ | 13.5000 |
| 0.08 | 3.80 | 13.00 | $\frac{3}{8}$ | 0.3750 | $4\frac{1}{2}$ | 4.5000 | 14 | 14.0000 |
| 0.10 | 4.00 | 13.50 | $\frac{7}{16}$ | 0.4375 | $4\frac{3}{4}$ | 4.7500 | $14\frac{1}{2}$ | 14.5000 |
| 0.12 | 4.20 | 14.00 | $\frac{1}{2}$ | 0.5000 | 5 | 5.0000 | 15 | 15.0000 |
| 0.16 | 4.40 | 14.50 | $\frac{9}{16}$ | 0.5625 | $5\frac{1}{4}$ | 5.2500 | $15\frac{1}{2}$ | 15.5000 |
| 0.20 | 4.60 | 15.00 | $\frac{5}{8}$ | 0.6250 | $5\frac{1}{2}$ | 5.5000 | 16 | 16.0000 |
| 0.24 | 4.80 | 15.50 | $1\frac{1}{16}$ | 0.6875 | $5\frac{3}{4}$ | 5.7500 | $16\frac{1}{2}$ | 16.5000 |
| 0.30 | 5.00 | 16.00 | $\frac{3}{4}$ | 0.7500 | 6 | 6.0000 | 17 | 17.0000 |
| 0.40 | 5.20 | 16.50 | $\frac{7}{8}$ | 0.8750 | $6\frac{1}{2}$ | 6.5000 | $17\frac{1}{2}$ | 17.5000 |
| 0.50 | 5.40 | 17.00 | 1 | 1.0000 | 7 | 7.0000 | 18 | 18.0000 |
| 0.60 | 5.60 | 17.50 | $1\frac{1}{4}$ | 1.2500 | $7\frac{1}{2}$ | 7.5000 | $18\frac{1}{2}$ | 18.5000 |
| 0.80 | 5.80 | 18.00 | $1\frac{1}{2}$ | 1.5000 | 8 | 8.0000 | 19 | 19.0000 |
| 1.00 | 6.00 | 18.50 | $1\frac{3}{4}$ | 1.7500 | $8\frac{1}{2}$ | 8.5000 | $19\frac{1}{2}$ | 19.5000 |
| 1.20 | 6.50 | 19.00 | 2 | 2.0000 | 9 | 9.0000 | 20 | 20.0000 |
| 1.40 | 7.00 | 19.50 | ... | ... | ... | ... | ... | ... |
| 1.60 | 7.50 | 20.00 | ... | ... | ... | ... | ... | ... |
| 1.80 | 8.00 | ... | ... | ... | ... | ... | ... | ... |

All dimensions are in inches.

Table 2. Preferred Series of Tolerances and Allowances (In thousandths of an inch)

| | | | | | | | |
|------|-----|----|-----|-----|-----|-----|-----|
| 0.1 | 1 | 10 | 100 | 0.3 | 3 | 30 | ... |
| ... | 1.2 | 12 | 125 | ... | 3.5 | 35 | ... |
| 0.15 | 1.4 | 14 | ... | 0.4 | 4 | 40 | ... |
| ... | 1.6 | 16 | 160 | ... | 4.5 | 45 | ... |
| ... | 1.8 | 18 | ... | 0.5 | 5 | 50 | ... |
| 0.2 | 2 | 20 | 200 | 0.6 | 6 | 60 | ... |
| ... | 2.2 | 22 | ... | 0.7 | 7 | 70 | ... |
| 0.25 | 2.5 | 25 | 250 | 0.8 | 8 | 80 | ... |
| ... | 2.8 | 28 | ... | 0.9 | 9 | ... | ... |

Standard Tolerances.—The series of standard tolerances shown in Table 3 are so arranged that for any one grade they represent approximately similar production difficulties throughout the range of sizes. This table provides a suitable range from which appropriate tolerances for holes and shafts can be selected and enables standard gages to be used. The tolerances shown in Table 3 have been used in the succeeding tables for different classes of fits.

Relation of Machining Processes to Tolerance Grades

| MACHINING OPERATION | TOLERANCE GRADES | | | | | | | | | |
|----------------------|------------------|---|---|---|---|---|----|----|----|----|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Lapping & Honing | | | | | | | | | | |
| Cylindrical Grinding | | | | | | | | | | |
| Surface Grinding | | | | | | | | | | |
| Diamond Turning | | | | | | | | | | |
| Diamond Boring | | | | | | | | | | |
| Broaching | | | | | | | | | | |
| Reaming | | | | | | | | | | |
| Turning | | | | | | | | | | |
| Boring | | | | | | | | | | |
| Milling | | | | | | | | | | |
| Planing & Shaping | | | | | | | | | | |
| Drilling | | | | | | | | | | |

Table 3. ANSI Standard Tolerances for Cylindrical Parts

| Nominal Size, Inches | Grade | | | | | | | | | | |
|-------------------------|-------|---|------|------|-----|-----|-----|-----|-----|-----|-----|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
| Over | To | Tolerances in thousandths of an inch ^a | | | | | | | | | |
| 0 – 0.12 | | 0.12 | 0.15 | 0.25 | 0.4 | 0.6 | 1.0 | 1.6 | 2.5 | 4 | 6 |
| 0.12 – 0.24 | | 0.15 | 0.20 | 0.3 | 0.5 | 0.7 | 1.2 | 1.8 | 3.0 | 5 | 7 |
| 0.24 – 0.40 | | 0.15 | 0.25 | 0.4 | 0.6 | 0.9 | 1.4 | 2.2 | 3.5 | 6 | 9 |
| 0.40 – 0.71 | | 0.2 | 0.3 | 0.4 | 0.7 | 1.0 | 1.6 | 2.8 | 4.0 | 7 | 10 |
| 0.71 – 1.19 | | 0.25 | 0.4 | 0.5 | 0.8 | 1.2 | 2.0 | 3.5 | 5.0 | 8 | 12 |
| 1.19 – 1.97 | | 0.3 | 0.4 | 0.6 | 1.0 | 1.6 | 2.5 | 4.0 | 6 | 10 | 16 |
| 1.97 – 3.15 | | 0.3 | 0.5 | 0.7 | 1.2 | 1.8 | 3.0 | 4.5 | 7 | 12 | 18 |
| 3.15 – 4.73 | | 0.4 | 0.6 | 0.9 | 1.4 | 2.2 | 3.5 | 5 | 9 | 14 | 22 |
| 4.73 – 7.09 | | 0.5 | 0.7 | 1.0 | 1.6 | 2.5 | 4.0 | 6 | 10 | 16 | 25 |
| 7.09 – 9.85 | | 0.6 | 0.8 | 1.2 | 1.8 | 2.8 | 4.5 | 7 | 12 | 18 | 28 |
| 9.85 – 12.41 | | 0.6 | 0.9 | 1.2 | 2.0 | 3.0 | 5.0 | 8 | 12 | 20 | 30 |
| 12.41 – 15.75 | | 0.7 | 1.0 | 1.4 | 2.2 | 3.5 | 6 | 9 | 14 | 22 | 35 |
| 15.75 – 19.69 | | 0.8 | 1.0 | 1.6 | 2.5 | 4 | 6 | 10 | 16 | 25 | 40 |
| 19.69 – 30.09 | | 0.9 | 1.2 | 2.0 | 3 | 5 | 8 | 12 | 20 | 30 | 50 |
| 30.09 – 41.49 | | 1.0 | 1.6 | 2.5 | 4 | 6 | 10 | 16 | 25 | 40 | 60 |
| 41.49 – 56.19 | | 1.2 | 2.0 | 3 | 5 | 8 | 12 | 20 | 30 | 50 | 80 |
| 56.19 – 76.39 | | 1.6 | 2.5 | 4 | 6 | 10 | 16 | 25 | 40 | 60 | 100 |
| 76.39 – 100.9 | | 2.0 | 3 | 5 | 8 | 12 | 20 | 30 | 50 | 80 | 125 |
| 100.9 – 131.9 | | 2.5 | 4 | 6 | 10 | 16 | 25 | 40 | 60 | 100 | 160 |
| 131.9 – 171.9 | | 3 | 5 | 8 | 12 | 20 | 30 | 50 | 80 | 125 | 200 |
| 171.9 – 200 | | 4 | 6 | 10 | 16 | 25 | 40 | 60 | 100 | 160 | 250 |

^a All tolerances above heavy line are in accordance with American-British-Canadian (ABC) agreements.

Table 4. Designation of Standard Fits

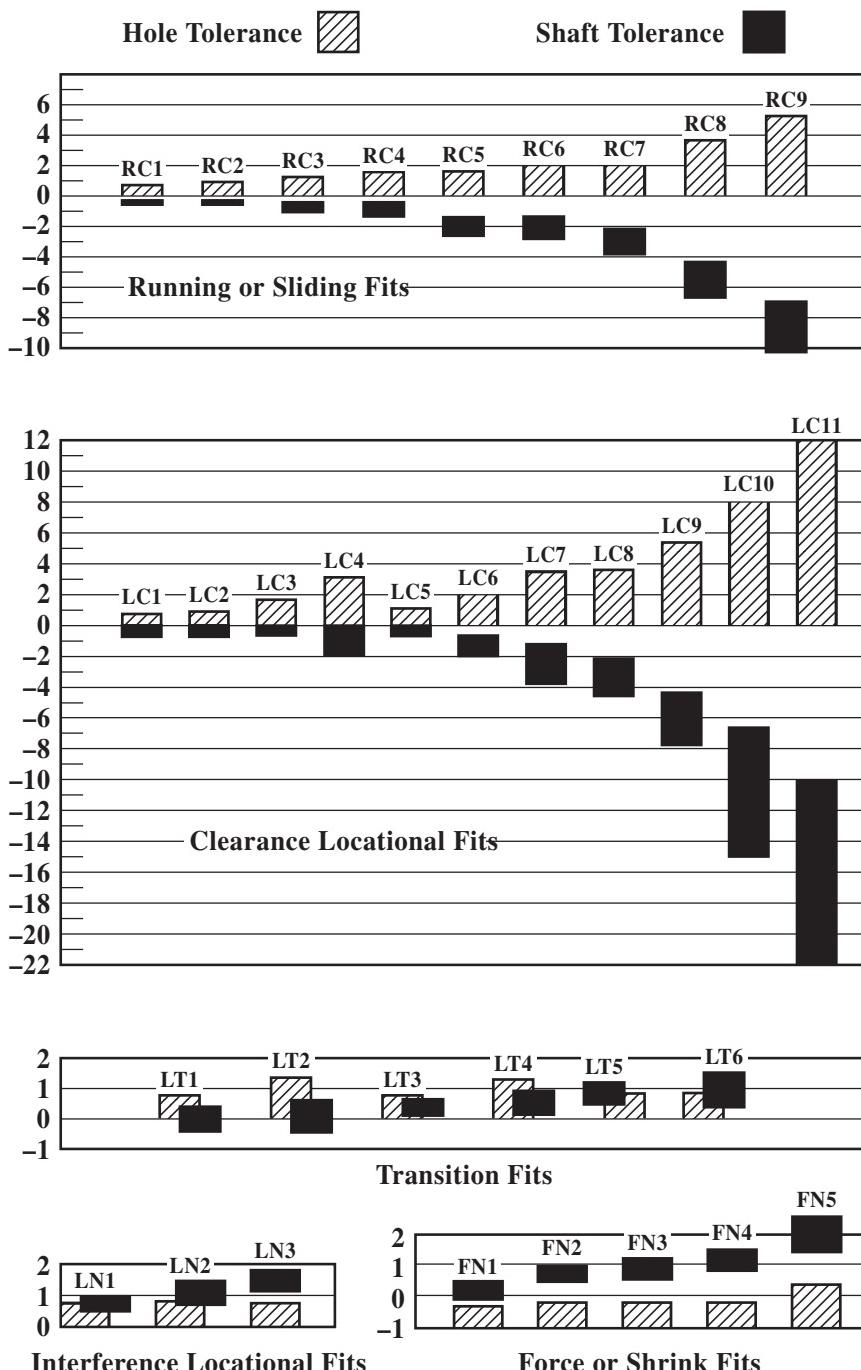
| Letter Symbols | Definition of Fits | Description |
|----------------|-------------------------------|---|
| RC | Running and Sliding Clearance | Intended to provide a similar running performance, with suitable lubrication allowance, throughout the range of sizes. |
| RC 1 | Close Sliding | Intended for the accurate location of parts that must be assembled without perceptible play. ^a |
| RC 2 | Sliding | Intended for accurate location, but with greater maximum clearance than class RC 1. Parts made to this fit move and turn easily but are not intended to run freely, and in large sizes may seize with small temperature changes. ^a |
| RC 3 | Precision Running | The closest fits that can be expected to run freely, intended for precision work at slow speeds and light journal pressures, but are not suitable where appreciable temperature differences are likely to be encountered. |
| RC 4 | Close Running | Intended chiefly for running fits on accurate machinery with moderate surface speeds and journal pressures, where accurate location and minimum play are desired. |
| RC 5 & RC 6 | Medium Running | Intended for higher running speeds, or heavy journal pressures, or both. |
| RC 7 | Free Running | Intended for use where accuracy is not essential, or where large temperature variations are likely to be encountered, or under both conditions. |
| RC 8 & RC 9 | Loose Running | Intended for use where wide commercial tolerances may be necessary, together with an allowance on the external member. |
| LC | Locational Clearance | Intended to determine only the location of the mating parts; they may provide rigid or accurate location, as with interference fits, or provide some freedom of location, as with clearance fits. |
| LC | Locational Clearance | Intended for parts that are normally stationary, but that can be freely assembled. They range from snug fits for parts requiring accuracy of location, through the medium clearance fits for parts such as spigots, to the looser fastener fits where freedom of assembly is of importance. |
| LT | Locational Transitional | A compromise between clearance and interference fits, for applications where accuracy of location is important, but a small amount of clearance or interference is permissible. |

Table 4. (Continued) Designation of Standard Fits

| Letter Symbols | Definition of Fits | Description |
|----------------|--|---|
| LN | Locational Interference | Used where accuracy of location is of prime importance, and for parts requiring rigidity and alignment with no special requirements for bore pressure. Not intended for parts designed to transmit frictional loads from one part to another by virtue of the tightness of fit. These conditions are covered by force fits. |
| FN | Force or Shrink | A special type of interference fit, normally characterized by maintenance of constant bore pressures throughout the range of sizes. The interference therefore varies almost directly with the diameter, and the difference between its minimum and maximum value is small, to maintain the resulting pressures within reasonable limits. |
| FN 1 | Light Drive | Requiring light assembly pressures, and producing more or less permanent assemblies. They are suitable for the thin sections or long fits, or in cast-iron external members. |
| FN 2 | Medium Drive | Suitable for ordinary steel parts, or for shrink fits on light sections. The tightest fits that can be used with high-grade cast iron external members. |
| FN 3 | Heavy Drive | Suitable for heavier steel parts or for shrink fits in medium sections. |
| FN 4 & FN 5 | Force | Suitable for parts that can be highly stressed, or for shrink fits where the heavy pressing forces required are impractical. |
| B | Bilateral Hole (Modified Standard Fit) | The symbols used for these fits are identical with those used for standard fits; thus, LC 4 B is a clearance locational fit, Class 4, except it is produced with a bilateral hole. |
| S | Basic Shaft (Modified Standard Fit) | The symbols used for these fits are identical with those used for standard fits; thus, LC 4 S is a clearance locational fit, Class 4, except it is produced on a basic shaft basis. |

^a Note: The clearances, used chiefly as slide fits, increase more slowly with the diameter than for other classes, so that accurate location is maintained even at the expense of free relative motion.

Graphical Representation of ANSI Limits and Fits.— A visual comparison of the hole and shaft tolerances and the clearances or interferences provided by the various types and classes of fits can be obtained from the diagrams on , which have been drawn to scale for a nominal diameter of 1 inch.



Diagrams show disposition of hole and shaft tolerances (in thousandths of an inch) with respect to basic size (0) for a diameter of 1 inch.

Table 5. American National Standard Running and Sliding Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class RC 1 | | | Class RC 2 | | | Class RC 3 | | | Class RC 4 | | |
|----------------------------|--|------------------------------|----------------|-----------------------------|------------------------------|----------------|-----------------------------|------------------------------|---------------|-----------------------------|------------------------------|--------------|
| | Clear- ance ^a | Standard Tolerance Limits | | Clearan- ce ^a | Standard Tolerance Limits | | Clearan- ce ^a | Standard Tolerance Limits | | Clearan- ce ^a | Standard Tolerance Limits | |
| | | Hole H5 | Shaft g4 | | Hole H6 | Shaft g5 | | Hole H7 | Shaft f6 | | Hole H8 | Shaft f7 |
| Over To | Values shown below are in thousandths of an inch | | | | | | | | | | | |
| 0– 0.12 | 0.1 0.45 | +0.2 0 | -0.1 -0.25 | 0.1 0.55 | +0.25 0 | -0.1 -0.3 | 0.3 0.95 | +0.4 0 | -0.3 -0.55 | 0.3 1.3 | +0.6 0 | -0.3 -0.7 |
| 0.12– 0.24 | 0.15 0.5 | +0.2 0 | -0.15 -0.3 | 0.15 0.65 | +0.3 0 | -0.15 -0.35 | 0.4 1.12 | +0.5 0 | -0.4 -0.7 | 0.4 1.6 | +0.7 0 | -0.4 -0.9 |
| 0.24– 0.40 | 0.2 0.6 | +0.25 0 | -0.2 -0.35 | 0.2 0.85 | +0.4 0 | -0.2 -0.45 | 0.5 1.5 | +0.6 0 | -0.5 -0.9 | 0.5 2.0 | +0.9 0 | -0.5 -1.1 |
| 0.40– 0.71 | 0.25 0.75 | +0.3 0 | -0.25 -0.45 | 0.25 0.95 | +0.4 0 | -0.25 -0.55 | 0.6 1.7 | +0.7 0 | -0.6 -1.0 | 0.6 2.3 | +1.0 0 | -0.6 -1.3 |
| 0.71– 1.19 | 0.3 0.95 | +0.4 0 | -0.3 -0.55 | 0.3 1.2 | +0.5 0 | -0.3 -0.7 | 0.8 2.1 | +0.8 0 | -0.8 -1.3 | 0.8 2.8 | +1.2 0 | -0.8 -1.6 |
| 1.19– 1.97 | 0.4 1.1 | +0.4 0 | -0.4 -0.7 | 0.4 1.4 | +0.6 0 | -0.4 -0.8 | 1.0 2.6 | +1.0 0 | -1.0 -1.6 | 1.0 3.6 | +1.6 0 | -1.0 -2.0 |
| 1.97– 3.15 | 0.4 1.2 | +0.5 0 | -0.4 -0.7 | 0.4 1.6 | +0.7 0 | -0.4 -0.9 | 1.2 3.1 | +1.2 0 | -1.2 -1.9 | 1.2 4.2 | +1.8 0 | -1.2 -2.4 |
| 3.15– 4.73 | 0.5 1.5 | +0.6 0 | -0.5 -0.9 | 0.5 2.0 | +0.9 0 | -0.5 -1.1 | 1.4 3.7 | +1.4 0 | -1.4 -2.3 | 1.4 5.0 | +2.2 0 | -1.4 -2.8 |
| 4.73– 7.09 | 0.6 1.8 | +0.7 0 | -0.6 -1.1 | 0.6 2.3 | +1.0 0 | -0.6 -1.3 | 1.6 4.2 | +1.6 0 | -1.6 -2.6 | 1.6 5.7 | +2.5 0 | -1.6 -3.2 |
| 7.09– 9.85 | 0.6 2.0 | +0.8 0 | -0.6 -1.2 | 0.6 2.6 | +1.2 0 | -0.6 -1.4 | 2.0 5.0 | +1.8 0 | -2.0 -3.2 | 2.0 6.6 | +2.8 0 | -2.0 -3.8 |
| 9.85– 12.41 | 0.8 2.3 | +0.9 0 | -0.8 -1.4 | 0.8 2.9 | +1.2 0 | -0.8 -1.7 | 2.5 5.7 | +2.0 0 | -2.5 -3.7 | 2.5 7.5 | +3.0 0 | -2.5 -4.5 |
| 12.41– 15.75 | 1.0 2.7 | +1.0 0 | -1.0 -1.7 | 1.0 3.4 | +1.4 0 | -1.0 -2.0 | 3.0 6.6 | +2.2 0 | -3.0 -4.4 | 3.0 8.7 | +3.5 0 | -3.0 -5.2 |
| 15.75– 19.69 | 1.2 3.0 | +1.0 0 | -1.2 -2.0 | 1.2 3.8 | +1.6 0 | -1.2 -2.2 | 4.0 8.1 | +2.5 0 | -4.0 -5.6 | 4.0 10.5 | +4.0 0 | -4.0 -6.5 |

^aPairs of values shown represent minimum and maximum amounts of clearance resulting from application of standard tolerance limits.

Table 6. American National Standard Running and Sliding Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class RC 5 | | | | Class RC 6 | | | | Class RC 7 | | | | Class RC 8 | | | | Class RC 9 | | | |
|----------------------------------|-----------------------------|------------------------------|-----------------|-----------------------------|--|-----------------|-----------------------------|------------------------------|------------------|-----------------------------|------------------------------|------------------|-----------------------------|------------------------------|------------------|-----------------------------|------------------------------|-------|--|--|
| | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | | |
| | | Hole H8 | Shaft e7 | | Hole H9 | Shaft e8 | | Hole H9 | Shaft d8 | | Hole H10 | Shaft c9 | | Hole H11 | Shaft | | Hole H11 | Shaft | | |
| | | Over | To | | Values shown below are in thousandths of an inch | | | | | | | | | | | | | | | |
| 0 – 0.12 | 0.6 1.6 | +0.6 0 | – 0.6 – 1.0 | 0.6 2.2 | +1.0 0 | – 0.6 – 1.2 | 1.0 2.6 | +1.0 0 | – 1.0 – 1.6 | 2.5 5.1 | +1.6 0 | – 2.5 – 3.5 | 4.0 8.1 | +2.5 0 | – 4.0 – 5.6 | | | | | |
| 0.12 – 0.24 | 0.8 2.0 | +0.7 0 | – 0.8 – 1.3 | 0.8 2.7 | +1.2 0 | – 0.8 – 1.5 | 1.2 3.1 | +1.2 0 | – 1.2 – 1.9 | 2.8 5.8 | +1.8 0 | – 2.8 – 4.0 | 4.5 9.0 | +3.0 0 | – 4.5 – 6.0 | | | | | |
| 0.24 – 0.40 | 1.0 2.5 | +0.9 0 | – 1.0 – 1.6 | 1.0 3.3 | +1.4 0 | – 1.0 – 1.9 | 1.6 3.9 | +1.4 0 | – 1.6 – 2.5 | 3.0 6.6 | +2.2 0 | – 3.0 – 4.4 | 5.0 10.7 | +3.5 0 | – 5.0 – 7.2 | | | | | |
| 0.40 – 0.71 | 1.2 2.9 | +1.0 0 | – 1.2 – 1.9 | 1.2 3.8 | +1.6 0 | – 1.2 – 2.2 | 2.0 4.6 | +1.6 0 | – 2.0 – 3.0 | 3.5 7.9 | +2.8 0 | – 3.5 – 5.1 | 6.0 12.8 | +4.0 0 | – 6.0 – 8.8 | | | | | |
| 0.71 – 1.19 | 1.6 3.6 | +1.2 0 | – 1.6 – 2.4 | 1.6 4.8 | +2.0 0 | – 1.6 – 2.8 | 2.5 5.7 | +2.0 0 | – 2.5 – 3.7 | 4.5 10.0 | +3.5 0 | – 4.5 – 6.5 | 7.0 15.5 | +5.0 0 | – 7.0 – 10.5 | | | | | |
| 1.19 – 1.97 | 2.0 4.6 | +1.6 0 | – 2.0 – 3.0 | 2.0 6.1 | +2.5 0 | – 2.0 – 3.6 | 3.0 7.1 | +2.5 0 | – 3.0 – 4.6 | 5.0 11.5 | +4.0 0 | – 5.0 – 7.5 | 8.0 18.0 | +6.0 0 | – 8.0 – 12.0 | | | | | |
| 1.97 – 3.15 | 2.5 5.5 | +1.8 0 | – 2.5 – 3.7 | 2.5 7.3 | +3.0 0 | – 2.5 – 4.3 | 4.0 8.8 | +3.0 0 | – 4.0 – 5.8 | 6.0 13.5 | +4.5 0 | – 6.0 – 9.0 | 9.0 20.5 | +7.0 0 | – 9.0 – 13.5 | | | | | |
| 3.15 – 4.73 | 3.0 6.6 | +2.2 0 | – 3.0 – 4.4 | 3.0 8.7 | +3.5 0 | – 3.0 – 5.2 | 5.0 10.7 | +3.5 0 | – 5.0 – 7.2 | 7.0 15.5 | +5.0 0 | – 7.0 – 10.5 | 10.0 24.0 | +9.0 0 | – 10.0 – 15.0 | | | | | |
| 4.73 – 7.09 | 3.5 7.6 | +2.5 0 | – 3.5 – 5.1 | 3.5 10.0 | +4.0 0 | – 3.5 – 6.0 | 6.0 12.5 | +4.0 0 | – 6.0 – 8.5 | 8.0 18.0 | +6.0 0 | – 8.0 – 12.0 | 12.0 28.0 | +10.0 0 | – 12.0 – 18.0 | | | | | |
| 7.09 – 9.85 | 4.0 8.6 | +2.8 0 | – 4.0 – 5.8 | 4.0 11.3 | +4.5 0 | – 4.0 – 6.8 | 7.0 14.3 | +4.5 0 | – 7.0 – 9.8 | 10.0 21.5 | +7.0 0 | – 10.0 – 14.5 | 15.0 34.0 | +12.0 0 | – 15.0 – 22.0 | | | | | |
| 9.85 – 12.41 | 5.0 10.0 | +3.0 0 | – 5.0 – 7.0 | 5.0 13.0 | +5.0 0 | – 5.0 – 8.0 | 8.0 16.0 | +5.0 0 | – 8.0 – 11.0 | 12.0 25.0 | +8.0 0 | – 12.0 – 17.0 | 18.0 38.0 | +12.0 0 | – 18.0 – 26.0 | | | | | |
| 12.41 – 15.75 | 6.0 11.7 | +3.5 0 | – 6.0 – 8.2 | 6.0 15.5 | +6.0 0 | – 6.0 – 9.5 | 10.0 19.5 | +6.0 0 | – 10.0 – 13.5 | 14.0 29.0 | +9.0 0 | – 14.0 – 20.0 | 22.0 45.0 | +14.0 0 | – 22.0 – 31.0 | | | | | |
| 15.75 – 19.69 | 8.0 14.5 | +4.0 0 | – 8.0 – 10.5 | 8.0 18.0 | +6.0 0 | – 8.0 – 12.0 | 12.0 22.0 | +6.0 0 | – 12.0 – 16.0 | 16.0 32.0 | +10.0 0 | – 16.0 – 22.0 | 25.0 51.0 | +16.0 0 | – 25.0 – 35.0 | | | | | |

Tolerance limits given in body of table are added to or subtracted from basic size (as indicated by + or – sign) to obtain maximum and minimum sizes of mating parts. All data above heavy lines are in accord with ABC agreements. Symbols H5, g4, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are also given in the ANSI Standard.

Table 7. American National Standard Clearance Locational Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class LC 1 | | | Class LC 2 | | | Class LC 3 | | | Class LC 4 | | | Class LC 5 | | |
|----------------------------|--|---------------------------|------------|-----------------------------|---------------------------|------------|-----------------------------|---------------------------|-----------|-----------------------------|---------------------------|-----------|-----------------------------|---------------------------|----------------|
| | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | | Clear- ance ^a | Standard Tolerance Limits | |
| | | Hole H6 | Shaft h5 | | Hole H7 | Shaft h6 | | Hole H8 | Shaft h7 | | Hole H10 | Shaft h9 | | Hole H7 | Shaft g6 |
| Over To | Values shown below are in thousandths of an inch | | | | | | | | | | | | | | |
| 0– 0.12 | 0 0.45 | +0.25 0 | 0 −0.2 | 0 0.65 | +0.4 0 | 0 −0.25 | 0 1 | +0.6 0 | 0 −0.4 | 0 2.6 | +1.6 0 | 0 −1.0 | 0.1 0.75 | +0.4 0 | −0.1 −0.35 |
| 0.12– 0.24 | 0 0.5 | +0.3 0 | 0 −0.2 | 0 0.8 | +0.5 0 | 0 −0.3 | 0 1.2 | +0.7 0 | 0 −0.5 | 0 3.0 | +1.8 0 | 0 −1.2 | 0.15 0.95 | +0.5 0 | −0.15 −0.45 |
| 0.24– 0.40 | 0 0.65 | +0.4 0 | 0 −0.25 | 0 1.0 | +0.6 0 | 0 −0.4 | 0 1.5 | +0.9 0 | 0 −0.6 | 0 3.6 | +2.2 0 | 0 −1.4 | 0.2 1.2 | +0.6 0 | −0.2 −0.6 |
| 0.40– 0.71 | 0 0.7 | +0.4 0 | 0 −0.3 | 0 1.1 | +0.7 0 | 0 −0.4 | 0 1.7 | +1.0 0 | 0 −0.7 | 0 4.4 | +2.8 0 | 0 −1.6 | 0.25 1.35 | +0.7 0 | −0.25 −0.65 |
| 0.71– 1.19 | 0 0.9 | +0.5 0 | 0 −0.4 | 0 1.3 | +0.8 0 | 0 −0.5 | 0 2 | +1.2 0 | 0 −0.8 | 0 5.5 | +3.5 0 | 0 −2.0 | 0.3 1.6 | +0.8 0 | −0.3 −0.8 |
| 1.19– 1.97 | 0 1.0 | +0.6 0 | 0 −0.4 | 0 1.6 | +1.0 0 | 0 −0.6 | 0 2.6 | +1.6 0 | 0 −1 | 0 6.5 | +4.0 0 | 0 −2.5 | 0.4 2.0 | +1.0 0 | −0.4 −1.0 |
| 1.97– 3.15 | 0 1.2 | +0.7 0 | 0 −0.5 | 0 1.9 | +1.2 0 | 0 −0.7 | 0 3 | +1.8 0 | 0 −1.2 | 0 7.5 | +4.5 0 | 0 −3 | 0.4 2.3 | +1.2 0 | −0.4 −1.1 |
| 3.15– 4.73 | 0 1.5 | +0.9 0 | 0 −0.6 | 0 2.3 | +1.4 0 | 0 −0.9 | 0 3.6 | +2.2 0 | 0 −1.4 | 0 8.5 | +5.0 0 | 0 −3.5 | 0.5 2.8 | +1.4 0 | −0.5 −1.4 |
| 4.73– 7.09 | 0 1.7 | +1.0 0 | 0 −0.7 | 0 2.6 | +1.6 0 | 0 −1.0 | 0 4.1 | +2.5 0 | 0 −1.6 | 0 10.0 | +6.0 0 | 0 −4 | 0.6 3.2 | +1.6 0 | −0.6 −1.6 |
| 7.09– 9.85 | 0 2.0 | +1.2 0 | 0 −0.8 | 0 3.0 | +1.8 0 | 0 −1.2 | 0 4.6 | +2.8 0 | 0 −1.8 | 0 11.5 | +7.0 0 | 0 −4.5 | 0.6 3.6 | +1.8 0 | −0.6 −1.8 |
| 9.85– 12.41 | 0 2.1 | +1.2 0 | 0 −0.9 | 0 3.2 | +2.0 0 | 0 −1.2 | 0 5 | +3.0 0 | 0 −2.0 | 0 13.0 | +8.0 0 | 0 −5 | 0.7 3.9 | +2.0 0 | −0.7 −1.9 |
| 12.41– 15.75 | 0 2.4 | +1.4 0 | 0 −1.0 | 0 3.6 | +2.2 0 | 0 −1.4 | 0 5.7 | +3.5 0 | 0 −2.2 | 0 15.0 | +9.0 0 | 0 −6 | 0.7 4.3 | +2.2 0 | −0.7 −2.1 |
| 15.75– 19.69 | 0 2.6 | +1.6 0 | 0 −1.0 | 0 4.1 | +2.5 0 | 0 −1.6 | 0 6.5 | +4 0 | 0 −2.5 | 0 16.0 | +10.0 0 | 0 −6 | 0.8 4.9 | +2.5 0 | −0.8 −2.4 |

^aPairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Table 8. American National Standard Clearance Locational Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class LC 6 | | | Class LC 7 | | | Class LC 8 | | | Class LC 9 | | | Class LC 10 | | | Class LC 11 | | |
|--|-----------------------------|-------------------------|--------------|-----------------------------|-------------------------|--------------|-----------------------------|-------------------------|--------------|-----------------------------|-------------------------|---------------|-----------------------------|-------------------------|--------------|-----------------------------|-------------------------|------------|
| | Clearan- ce ^a | Std.Tolerance Limits | | Clearan- ce ^a | Std.Tolerance Limits | | Clearan- ce ^a | Std.Tolerance Limits | | Clearan- ce ^a | Std.Tolerance Limits | | Clearan- ce ^a | Std.Tolerance Limits | | Clearan- ce ^a | Std.Tolerance Limits | |
| | | Hole H9 | Shaft f8 | | Hole H10 | Shaft e9 | | Hole H10 | Shaft d9 | | Hole H11 | Shaft c10 | | Hole H12 | Shaft | | Hole H13 | Shaft |
| Values shown below are in thousandths of an inch | | | | | | | | | | | | | | | | | | |
| 0– 0.12 | 0.3 1.9 | +1.0 0 | -0.3 -0.9 | 0.6 3.2 | +1.6 0 | -0.6 -1.6 | 1.0 2.0 | +1.6 0 | -1.0 -2.0 | 2.5 6.6 | +2.5 0 | -2.5 -4.1 | 4 12 | +4 0 | -4 -8 | 5 17 | +6 0 | -5 -11 |
| 0.12– 0.24 | 0.4 2.3 | +1.2 0 | -0.4 -1.1 | 0.8 3.8 | +1.8 0 | -0.8 -2.0 | 1.2 4.2 | +1.8 0 | -1.2 -2.4 | 2.8 7.6 | +3.0 0 | -2.8 -4.6 | 4.5 14.5 | +5 0 | -4.5 -9.5 | 6 20 | +7 0 | -6 -13 |
| 0.24– 0.40 | 0.5 2.8 | +1.4 0 | -0.5 -1.4 | 1.0 4.6 | +2.2 0 | -1.0 -2.4 | 1.6 5.2 | +2.2 0 | -1.6 -3.0 | 3.0 8.7 | +3.5 0 | -3.0 -5.2 | 5 17 | +6 0 | -5 -11 | 7 25 | +9 0 | -7 -16 |
| 0.40– 0.71 | 0.6 3.2 | +1.6 0 | -0.6 -1.6 | 1.2 5.6 | +2.8 0 | -1.2 -2.8 | 2.0 6.4 | +2.8 0 | -2.0 -3.6 | 3.5 10.3 | +4.0 0 | -3.5 -6.3 | 6 20 | +7 0 | -6 -13 | 8 28 | +10 0 | -8 -18 |
| 0.71– 1.19 | 0.8 4.0 | +2.0 0 | -0.8 -2.0 | 1.6 7.1 | +3.5 0 | -1.6 -3.6 | 2.5 8.0 | +3.5 0 | -2.5 -4.5 | 4.5 13.0 | +5.0 0 | -4.5 -8.0 | 7 23 | +8 0 | -7 -15 | 10 34 | +12 0 | -10 -22 |
| 1.19– 1.97 | 1.0 5.1 | +2.5 0 | -1.0 -2.6 | 2.0 8.5 | +4.0 0 | -2.0 -4.5 | 3.6 9.5 | +4.0 0 | -3.0 -5.5 | 5.0 15.0 | +6 0 | -5.0 -9.0 | 8 28 | +10 0 | -8 -18 | 12 44 | +16 0 | -12 -28 |
| 1.97– 3.15 | 1.2 6.0 | +3.0 0 | -1.0 -3.0 | 2.5 10.0 | +4.5 0 | -2.5 -5.5 | 4.0 11.5 | +4.5 0 | -4.0 -7.0 | 6.0 17.5 | +7 0 | -6.0 -10.5 | 10 34 | +12 0 | -10 -22 | 14 50 | +18 0 | -14 -32 |
| 3.15– 4.73 | 1.4 7.1 | +3.5 0 | -1.4 -3.6 | 3.0 11.5 | +5.0 0 | -3.0 -6.5 | 5.0 13.5 | +5.0 0 | -5.0 -8.5 | 7 21 | +9 0 | -7 -12 | 11 39 | +14 0 | -11 -25 | 16 60 | +22 0 | -16 -38 |
| 4.73– 7.09 | 1.6 8.1 | +4.0 0 | -1.6 -4.1 | 3.5 13.5 | +6.0 0 | -3.5 -7.5 | 6 16 | +6 0 | -6 -10 | 8 24 | +10 0 | -8 -14 | 12 44 | +16 0 | -12 -28 | 18 68 | +25 0 | -18 -43 |
| 7.09– 9.85 | 2.0 9.3 | +4.5 0 | -2.0 -4.8 | 4.0 15.5 | +7.0 0 | -4.0 -8.5 | 7 18.5 | +7 0 | -7 -11.5 | 10 29 | +12 0 | -10 -17 | 16 52 | +18 0 | -16 -34 | 22 78 | +28 0 | -22 -50 |
| 9.85– 12.41 | 2.2 10.2 | +5.0 0 | -2.2 -5.2 | 4.5 17.5 | +8.0 0 | -4.5 -9.5 | 7 20 | +8 0 | -7 -12 | 12 32 | +12 0 | -12 -20 | 20 60 | +20 0 | -20 -40 | 28 88 | +30 0 | -28 -58 |
| 12.41– 15.75 | 2.5 12.0 | +6.0 0 | -2.5 -6.0 | 5.0 20.0 | +9.0 0 | -5 -11 | 8 23 | +9 0 | -8 -14 | 14 37 | +14 0 | -14 -23 | 22 66 | +22 0 | -22 -44 | 30 100 | +35 0 | -30 -65 |
| 15.75– 19.69 | 2.8 12.8 | +6.0 0 | -2.8 -6.8 | 5.0 21.0 | +10.0 0 | -5 -11 | 9 25 | +10 0 | -9 -15 | 16 42 | +16 0 | -16 -26 | 25 75 | +25 0 | -25 -50 | 35 115 | +40 0 | -35 -75 |

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or - sign) to obtain maximum and minimum sizes of mating parts. All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

Table 9. ANSI Standard Transition Locational Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class LT 1 | | | Class LT 2 | | | Class LT 3 | | | Class LT 4 | | | Class LT 5 | | | Class LT 6 | | |
|----------------------------------|------------------|--|----------------|------------------|-----------------------------|----------------|------------------|-----------------------------|--------------|------------------|-----------------------------|--------------|------------------|-----------------------------|---------------|------------------|-----------------------------|----------------|
| | Fit ^a | Std. Tolerance Limits | | Fit ^a | Std. Tolerance Limits | | Fit ^a | Std. Tolerance Limits | | Fit ^a | Std. Tolerance Limits | | Fit ^a | Std. Tolerance Limits | | Fit ^a | Std. Tolerance Limits | |
| | | Hole H7 | Shaft js6 | | Hole H8 | Shaft js7 | | Hole H7 | Shaft k6 | | Hole H8 | Shaft k7 | | Hole H7 | Shaft n6 | | Hole H7 | Shaft n7 |
| Over To | | Values shown below are in thousandths of an inch | | | | | | | | | | | | | | | | |
| 0– 0.12 | -0.12 +0.52 | +0.4 0 | +0.12 -0.12 | -0.2 +0.8 | +0.6 0 | +0.2 -0.2 | ... | ... | ... | ... | ... | ... | -0.5 +0.15 | +0.4 0 | +0.5 +0.25 | -0.65 +0.15 | +0.4 0 | +0.65 +0.25 |
| 0.12– 0.24 | -0.15 +0.65 | +0.5 0 | +0.15 -0.15 | -0.25 +0.95 | +0.7 0 | +0.25 -0.25 | ... | ... | ... | ... | ... | ... | -0.6 +0.2 | +0.5 0 | +0.6 +0.3 | -0.8 +0.2 | +0.5 0 | +0.8 +0.3 |
| 0.24– 0.40 | -0.2 +0.8 | +0.6 0 | +0.2 -0.2 | -0.3 +1.2 | +0.9 0 | +0.3 -0.3 | -0.5 +0.5 | +0.6 0 | +0.5 +0.1 | -0.7 +0.8 | +0.9 0 | +0.7 +0.1 | -0.8 +0.2 | +0.6 0 | +0.8 +0.4 | -1.0 +0.4 | +0.6 +0.2 | +1.0 +0.4 |
| 0.40– 0.71 | -0.2 +0.9 | +0.7 0 | +0.2 -0.2 | -0.35 +1.35 | +1.0 0 | +0.35 -0.35 | -0.5 +0.6 | +0.7 0 | +0.5 +0.1 | -0.8 +0.9 | +1.0 0 | +0.8 +0.1 | -0.9 +0.2 | +0.7 0 | +0.9 +0.5 | -1.2 +0.2 | +0.7 +0.2 | +1.2 +0.5 |
| 0.71– 1.19 | -0.25 +1.05 | +0.8 0 | +0.25 -0.25 | -0.4 +1.6 | +1.2 0 | +0.4 -0.4 | -0.6 +0.7 | +0.8 0 | +0.6 +0.1 | -0.9 +1.1 | +1.2 0 | +0.9 +0.1 | -1.1 +0.2 | +0.8 0 | +1.1 +0.6 | -1.4 +0.2 | +0.8 +0.2 | +1.4 +0.6 |
| 1.19– 1.97 | -0.3 +1.3 | +1.0 0 | +0.3 -0.3 | -0.5 +2.1 | +1.6 0 | +0.5 -0.5 | -0.7 +0.9 | +1.0 0 | +0.7 +0.1 | -1.1 +1.5 | +1.6 0 | +1.1 +0.1 | -1.3 +0.3 | +1.0 0 | +1.3 +0.7 | -1.7 +0.3 | +1.0 +0.3 | +1.7 +0.7 |
| 1.97– 3.15 | -0.3 +1.5 | +1.2 0 | +0.3 -0.3 | -0.6 +2.4 | +1.8 0 | +0.6 -0.6 | -0.8 +1.1 | +1.2 0 | +0.8 +0.1 | -1.3 +1.7 | +1.8 0 | +1.3 +0.1 | -1.5 +0.4 | +1.2 0 | +1.5 +0.8 | -2.0 +0.4 | +1.2 +0.4 | +2.0 +0.8 |
| 3.15– 4.73 | -0.4 +1.8 | +1.4 0 | +0.4 -0.4 | -0.7 +2.9 | +2.2 0 | +0.7 -0.7 | -1.0 +1.3 | +1.4 0 | +1.0 +0.1 | -1.5 +2.1 | +2.2 0 | +1.5 +0.1 | -1.9 +0.4 | +1.4 0 | +1.9 +1.0 | -2.4 +0.4 | +1.4 +0.4 | +2.4 +1.0 |
| 4.73– 7.09 | -0.5 +2.1 | +1.6 0 | +0.5 -0.5 | -0.8 +3.3 | +2.5 0 | +0.8 -0.8 | -1.1 +1.5 | +1.6 0 | +1.1 +0.1 | -1.7 +2.4 | +2.5 0 | +1.7 +0.1 | -2.2 +0.4 | +1.6 0 | +2.2 +1.2 | -2.8 +0.4 | +1.6 +0.4 | +2.8 +1.2 |
| 7.09– 9.85 | -0.6 +2.4 | +1.8 0 | +0.6 -0.6 | -0.9 +3.7 | +2.8 0 | +0.9 -0.9 | -1.4 +1.6 | +1.8 0 | +1.4 +0.2 | -2.0 +2.6 | +2.8 0 | +2.0 +0.2 | -2.6 +0.4 | +1.8 0 | +2.6 +1.4 | -3.2 +0.4 | +1.8 +0.4 | +3.2 +1.4 |
| 9.85– 12.41 | -0.6 +2.6 | +2.0 0 | +0.6 -6.6 | -1.0 +4.0 | +3.0 0 | +1.0 -1.0 | -1.4 +1.8 | +2.0 0 | +1.4 +0.2 | -2.2 +2.8 | +3.0 0 | +2.2 +0.2 | -2.6 +0.6 | +2.0 0 | +2.6 +1.4 | -3.4 +0.6 | +2.0 +0.6 | +3.4 +1.4 |
| 12.41– 15.75 | -0.7 +2.9 | +2.2 0 | +0.7 -0.7 | -1.0 +4.5 | +3.5 0 | +1.0 -1.0 | -1.6 +2.0 | +2.2 0 | +1.6 +0.2 | -2.4 +3.3 | +3.5 0 | +2.4 +0.2 | -3.0 +0.6 | +2.2 0 | +3.0 +1.6 | -3.8 +0.6 | +2.2 +0.6 | +3.8 +1.6 |
| 15.75– 19.69 | -0.8 +3.3 | +2.5 0 | +0.8 -0.8 | -1.2 +5.2 | +4.0 0 | +1.2 -1.2 | -1.8 +2.3 | +2.5 0 | +1.8 +0.2 | -2.7 +3.8 | +4.0 0 | +2.7 +0.2 | -3.4 +0.7 | +2.5 0 | +3.4 +1.8 | -4.3 +0.7 | +2.5 0 | +4.3 +1.8 |

^aPairs of values shown represent maximum amount of interference (–) and maximum amount of clearance (+) resulting from application of standard tolerance limits. All data above heavy lines are in accord with ABC agreements. Symbols H7, js6, etc., are hole and shaft designations in the ABC system.

Table 10. ANSI Standard Interference Location Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class LN 1 | | | Class LN 2 | | | Class LN 3 | | |
|----------------------------|--|-----------------|----------|------------------------|-----------------|----------|------------------------|-----------------|----------|
| | Limits of Interference | Standard Limits | | Limits of Interference | Standard Limits | | Limits of Interference | Standard Limits | |
| | | Hole H6 | Shaft n5 | | Hole H7 | Shaft p6 | | Hole H7 | Shaft r6 |
| Over To | Values shown below are in thousandths of an inch | | | | | | | | |
| 0 – 0.12 | 0 | +0.25 | +0.45 | 0 | +0.4 | +0.65 | 0.1 | +0.4 | +0.75 |
| | 0.45 | 0 | +0.25 | 0.65 | 0 | +0.4 | 0.75 | 0 | +0.5 |
| 0.12 – 0.24 | 0 | +0.3 | +0.5 | 0 | +0.5 | +0.8 | 0.1 | +0.5 | +0.9 |
| | 0.5 | 0 | +0.3 | 0.8 | 0 | +0.5 | 0.9 | 0 | +0.6 |
| 0.24 – 0.40 | 0 | +0.4 | +0.65 | 0 | +0.6 | +1.0 | 0.2 | +0.6 | +1.2 |
| | 0.65 | 0 | +0.4 | 1.0 | 0 | +0.6 | 1.2 | 0 | +0.8 |
| 0.40 – 0.71 | 0 | +0.4 | +0.8 | 0 | +0.7 | +1.1 | 0.3 | +0.7 | +1.4 |
| | 0.8 | 0 | +0.4 | 1.1 | 0 | +0.7 | 1.4 | 0 | +1.0 |
| 0.71 – 1.19 | 0 | +0.5 | +1.0 | 0 | +0.8 | +1.3 | 0.4 | +0.8 | +1.7 |
| | 1.0 | 0 | +0.5 | 1.3 | 0 | +0.8 | 1.7 | 0 | +1.2 |
| 1.19 – 1.97 | 0 | +0.6 | +1.1 | 0 | +1.0 | +1.6 | 0.4 | +1.0 | +2.0 |
| | 1.1 | 0 | +0.6 | 1.6 | 0 | +1.0 | 2.0 | 0 | +1.4 |
| 1.97 – 3.15 | 0.1 | +0.7 | +1.3 | 0.2 | +1.2 | +2.1 | 0.4 | +1.2 | +2.3 |
| | 1.3 | 0 | +0.8 | 2.1 | 0 | +1.4 | 2.3 | 0 | +1.6 |
| 3.15 – 4.73 | 0.1 | +0.9 | +1.6 | 0.2 | +1.4 | +2.5 | 0.6 | +1.4 | +2.9 |
| | 1.6 | 0 | +1.0 | 2.5 | 0 | +1.6 | 2.9 | 0 | +2.0 |
| 4.73 – 7.09 | 0.2 | +1.0 | +1.9 | 0.2 | +1.6 | +2.8 | 0.9 | +1.6 | +3.5 |
| | 1.9 | 0 | +1.2 | 2.8 | 0 | +1.8 | 3.5 | 0 | +2.5 |
| 7.09 – 9.85 | 0.2 | +1.2 | +2.2 | 0.2 | +1.8 | +3.2 | 1.2 | +1.8 | +4.2 |
| | 2.2 | 0 | +1.4 | 3.2 | 0 | +2.0 | 4.2 | 0 | +3.0 |
| 9.85 – 12.41 | 0.2 | +1.2 | +2.3 | 0.2 | +2.0 | +3.4 | 1.5 | +2.0 | +4.7 |
| | 2.3 | 0 | +1.4 | 3.4 | 0 | +2.2 | 4.7 | 0 | +3.5 |
| 12.41 – 15.75 | 0.2 | +1.4 | +2.6 | 0.3 | +2.2 | +3.9 | 2.3 | +2.2 | +5.9 |
| | 2.6 | 0 | +1.6 | 3.9 | 0 | +2.5 | 5.9 | 0 | +4.5 |
| 15.75 – 19.69 | 0.2 | +1.6 | +2.8 | 0.3 | +2.5 | +4.4 | 2.5 | +2.5 | +6.6 |
| | 2.8 | 0 | +1.8 | 4.4 | 0 | +2.8 | 6.6 | 0 | +5.0 |

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or - sign) to obtain maximum and minimum sizes of mating parts.

All data in this table are in accordance with American-British-Canadian (ABC) agreements.

Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

Symbols H7, p6, etc., are hole and shaft designations in the ABC system.

Table 11. ANSI Standard Force and Shrink Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class FN 1 | | | Class FN 2 | | | Class FN 3 | | | Class FN 4 | | | Class FN 5 | | |
|--|---------------------------|---------------------------|---------------|---------------------------|---------------------------|---------------|---------------------------|---------------------------|--------------|---------------------------|---------------------------|---------------|---------------------------|---------------------------|--------------|
| | Interference ^a | Standard Tolerance Limits | | Interference ^a | Standard Tolerance Limits | | Interference ^a | Standard Tolerance Limits | | Interference ^a | Standard Tolerance Limits | | Interference ^a | Standard Tolerance Limits | |
| | | Hole H6 | Shaft | | Hole H7 | Shaft s6 | | Hole H7 | Shaft t6 | | Hole H7 | Shaft u6 | | Hole H8 | Shaft x7 |
| Values shown below are in thousandths of an inch | | | | | | | | | | | | | | | |
| Over To | | | | | | | | | | | | | | | |
| 0 – 0.12 | 0.05 0.5 | +0.25 0 | +0.5 +0.3 | 0.2 0.85 | +0.4 0 | +0.85 +0.6 | ... | ... | ... | 0.3 0.95 | +0.4 0 | +0.95 +0.7 | 0.3 1.3 | +0.6 0 | +1.3 +0.9 |
| 0.12 – 0.24 | 0.1 0.6 | +0.3 0 | +0.6 +0.4 | 0.2 1.0 | +0.5 0 | +1.0 +0.7 | ... | ... | ... | 0.4 1.2 | +0.5 0 | +1.2 +0.9 | 0.5 1.7 | +0.7 0 | +1.7 +1.2 |
| 0.24 – 0.40 | 0.1 0.75 | +0.4 0 | +0.75 +0.5 | 0.4 1.4 | +0.6 0 | +1.4 +1.0 | ... | ... | ... | 0.6 1.6 | +0.6 0 | +1.6 +1.2 | 0.5 2.0 | +0.9 0 | +2.0 +1.4 |
| 0.40 – 0.56 | 0.1 0.8 | +0.4 0 | +0.8 +0.5 | 0.5 1.6 | +0.7 0 | +1.6 +1.2 | ... | ... | ... | 0.7 1.8 | +0.7 0 | +1.8 +1.4 | 0.6 2.3 | +1.0 0 | +2.3 +1.6 |
| 0.56 – 0.71 | 0.2 0.9 | +0.4 0 | +0.9 +0.6 | 0.5 1.6 | +0.7 0 | +1.6 +1.2 | ... | ... | ... | 0.7 1.8 | +0.7 0 | +1.8 +1.4 | 0.8 2.5 | +1.0 0 | +2.5 +1.8 |
| 0.71 – 0.95 | 0.2 1.1 | +0.5 0 | +1.1 +0.7 | 0.6 1.9 | +0.8 0 | +1.9 +1.4 | ... | ... | ... | 0.8 2.1 | +0.8 0 | +2.1 +1.6 | 1.0 3.0 | +1.2 0 | +3.0 +2.2 |
| 0.95 – 1.19 | 0.3 1.2 | +0.5 0 | +1.2 +0.8 | 0.6 1.9 | +0.8 0 | +1.9 +1.4 | 0.8 2.1 | +0.8 0 | +2.1 +1.6 | +1.0 2.3 | +0.8 0 | +2.3 +1.8 | 1.3 3.3 | +1.2 0 | +3.3 +2.5 |
| 1.19 – 1.58 | 0.3 1.3 | +0.6 0 | +1.3 +0.9 | 0.8 2.4 | +1.0 0 | +2.4 +1.8 | 1.0 2.6 | +1.0 0 | +2.6 +2.0 | 1.5 3.1 | +1.0 0 | +3.1 +2.5 | 1.4 4.0 | +1.6 0 | +4.0 +3.0 |
| 1.58 – 1.97 | 0.4 1.4 | +0.6 0 | +1.4 +1.0 | 0.8 2.4 | +1.0 0 | +2.4 +1.8 | 1.2 2.8 | +1.0 0 | +2.8 +2.2 | 1.8 3.4 | +1.0 0 | +3.4 +2.8 | 2.4 5.0 | +1.6 0 | +5.0 +4.0 |
| 1.97 – 2.56 | 0.6 1.8 | +0.7 0 | +1.8 +1.3 | 0.8 2.7 | +1.2 0 | +2.7 +2.0 | 1.3 3.2 | +1.2 0 | +3.2 +2.5 | 2.3 4.2 | +1.2 0 | +4.2 +3.5 | 3.2 6.2 | +1.8 0 | +6.2 +5.0 |
| 2.56 – 3.15 | 0.7 1.9 | +0.7 0 | +1.9 +1.4 | 1.0 2.9 | +1.2 0 | +2.9 +2.2 | 1.8 3.7 | +1.2 0 | +3.7 +3.0 | 2.8 4.7 | +1.2 0 | +4.7 +4.0 | 4.2 7.2 | +1.8 0 | +7.2 +6.0 |
| 3.15 – 3.94 | 0.9 2.4 | +0.9 0 | +2.4 +1.8 | 1.4 3.7 | +1.4 0 | +3.7 +2.8 | 2.1 4.4 | +1.4 0 | +4.4 +3.5 | 3.6 5.9 | +1.4 0 | +5.9 +5.0 | 4.8 8.4 | +2.2 0 | +8.4 +7.0 |
| 3.94 – 4.73 | 1.1 2.6 | +0.9 0 | +2.6 +2.0 | 1.6 3.9 | +1.4 0 | +3.9 +3.0 | 2.6 4.9 | +1.4 0 | +4.9 +4.0 | 4.6 6.9 | +1.4 0 | +6.9 +6.0 | 5.8 9.4 | +2.2 0 | +9.4 +8.0 |

Table 11. (Continued) ANSI Standard Force and Shrink Fits ANSI B4.1-1967, R2004

| Nominal Size Range, Inches | Class FN 1 | | | Class FN 2 | | | Class FN 3 | | | Class FN 4 | | | Class FN 5 | | |
|----------------------------------|--|------------------------------|--------------|--------------------------------|------------------------------|----------------|--------------------------------|------------------------------|----------------|--------------------------------|------------------------------|----------------|--------------------------------|------------------------------|----------------|
| | Inter- ference ^a | Standard Tolerance Limits | | Inter- ference ^a | Standard Tolerance Limits | | Inter- ference ^a | Standard Tolerance Limits | | Inter- ference ^a | Standard Tolerance Limits | | Inter- ference ^a | Standard Tolerance Limits | |
| | | Hole H6 | Shaft s6 | | Hole H7 | Shaft s6 | | Hole H7 | Shaft t6 | | Hole H7 | Shaft u6 | | Hole H8 | Shaft x7 |
| Over To | Values shown below are in thousandths of an inch | | | | | | | | | | | | | | |
| 4.73 – 5.52 | 1.2 2.9 | +1.0 0 | +2.9 +2.2 | 1.9 4.5 | +1.6 0 | +4.5 +3.5 | 3.4 6.0 | +1.6 0 | +6.0 +5.0 | 5.4 8.0 | +1.6 0 | +8.0 +7.0 | 7.5 11.6 | +2.5 0 | +11.6 +10.0 |
| 5.52 – 6.30 | 1.5 3.2 | +1.0 0 | +3.2 +2.5 | 2.4 5.0 | +1.6 0 | +5.0 +4.0 | 3.4 6.0 | +1.6 0 | +6.0 +5.0 | 5.4 8.0 | +1.6 0 | +8.0 +7.0 | 9.5 13.6 | +2.5 0 | +13.6 +12.0 |
| 6.30 – 7.09 | 1.8 3.5 | +1.0 0 | +3.5 +2.8 | 2.9 5.5 | +1.6 0 | +5.5 +4.5 | 4.4 7.0 | +1.6 0 | +7.0 +6.0 | 6.4 9.0 | +1.6 0 | +9.0 +8.0 | 9.5 13.6 | +2.5 0 | +13.6 +12.0 |
| 7.09 – 7.88 | 1.8 3.8 | +1.2 0 | +3.8 +3.0 | 3.2 6.2 | +1.8 0 | +6.2 +5.0 | 5.2 8.2 | +1.8 0 | +8.2 +7.0 | 7.2 10.2 | +1.8 0 | +10.2 +9.0 | 11.2 15.8 | +2.8 0 | +15.8 +14.0 |
| 7.88 – 8.86 | 2.3 4.3 | +1.2 0 | +4.3 +3.5 | 3.2 6.2 | +1.8 0 | +6.2 +5.0 | 5.2 8.2 | +1.8 0 | +8.2 +7.0 | 8.2 11.2 | +1.8 0 | +11.2 +10.0 | 13.2 17.8 | +2.8 0 | +17.8 +16.0 |
| 8.86 – 9.85 | 2.3 4.3 | +1.2 0 | +4.3 +3.5 | 4.2 7.2 | +1.8 0 | +7.2 +6.0 | 6.2 9.2 | +1.8 0 | +9.2 +8.0 | 10.2 13.2 | +1.8 0 | +13.2 +12.0 | 13.2 17.8 | +2.8 0 | +17.8 +16.0 |
| 9.85 – 11.03 | 2.8 4.9 | +1.2 0 | +4.9 +4.0 | 4.0 7.2 | +2.0 0 | +7.2 +6.0 | 7.0 10.2 | +2.0 0 | +10.2 +9.0 | 10.0 13.2 | +2.0 0 | +13.2 +12.0 | 15.0 20.0 | +3.0 0 | +20.0 +18.0 |
| 11.03 – 12.41 | 2.8 4.9 | +1.2 0 | +4.9 +4.0 | 5.0 8.2 | +2.0 0 | +8.2 +7.0 | 7.0 10.2 | +2.0 0 | +10.2 +9.0 | 12.0 15.2 | +2.0 0 | +15.2 +14.0 | 17.0 22.0 | +3.0 0 | +22.0 +20.0 |
| 12.41 – 13.98 | 3.1 5.5 | +1.4 0 | +5.5 +4.5 | 5.8 9.4 | +2.2 0 | +9.4 +8.0 | 7.8 11.4 | +2.2 0 | +11.4 +10.0 | 13.8 17.4 | +2.2 0 | +17.4 +16.0 | 18.5 24.2 | +3.5 0 | +24.2 +22.0 |
| 13.98 – 15.75 | 3.6 6.1 | +1.4 0 | +6.1 +5.0 | 5.8 9.4 | +2.2 0 | +9.4 +8.0 | 9.8 13.4 | +2.2 0 | +13.4 +12.0 | 15.8 19.4 | +2.2 0 | +19.4 +18.0 | 21.5 27.2 | +3.5 0 | +27.2 +25.0 |
| 15.75 – 17.72 | 4.4 7.0 | +1.6 0 | +7.0 +6.0 | 6.5 10.6 | +2.5 0 | +10.6 +9.0 | +9.5 13.6 | +2.5 0 | +13.6 +12.0 | 17.5 21.6 | +2.5 0 | +21.6 +20.0 | 24.0 30.5 | +4.0 0 | +30.5 +28.0 |
| 17.72 – 19.69 | 4.4 7.0 | +1.6 0 | +7.0 +6.0 | 7.5 11.6 | +2.5 0 | +11.6 +10.0 | 11.5 15.6 | +2.5 0 | +15.6 +14.0 | 19.5 23.6 | +2.5 0 | +23.6 +22.0 | 26.0 32.5 | +4.0 0 | +32.5 +30.0 |

^aPairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc., are hole and shaft designations in the ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI standard.

American National Standard Preferred Metric Limits and Fits.— This standard ANSI B4.2-1978 (R2004) describes the ISO system of metric limits and fits for mating parts as approved for general engineering usage in the United States. It establishes:

1) the designation symbols used to define dimensional limits on drawings, material stock, related tools, gages, etc.. (2) the preferred basic sizes (first and second choices). (3) the preferred tolerance zones (first, second, and third choices). (4) the definitions of related terms. (5) the preferred limits and fits for sizes (first choice only) up to and including 500 millimeters.

The general terms “hole” and “shaft” can also be taken to refer to the space containing or contained by two parallel faces of any part, such as the width of a slot, or the thickness of a key.

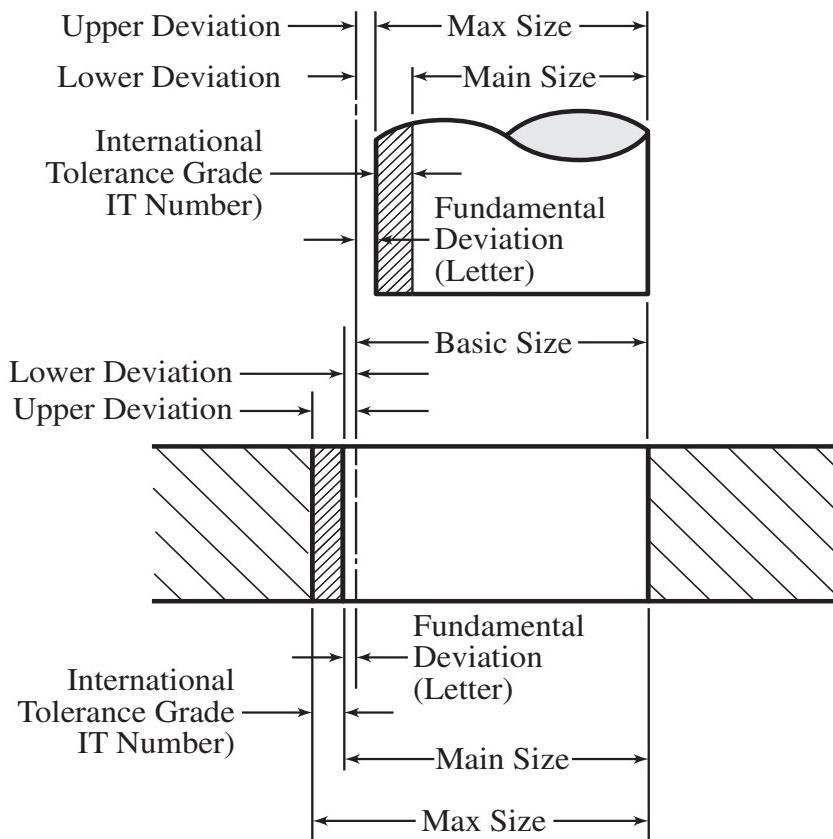


Fig. 1. Illustration of Definitions

Definitions.— The most important terms relating to limits and fits are shown in Fig. 1 and are defined as follows:

Basic Size: The size to which limits of deviation are assigned. The basic size is the same for both members of a fit. For example, it is designated by the numbers 40 in 40H7.

Deviation: The algebraic difference between a size and the corresponding basic size.

Upper Deviation: The algebraic difference between the maximum limit of size and the corresponding basic size.

**Table 12. American National Standard Preferred Metric Sizes
ANSI B4.2-1978, R2004**

| Basic Size, mm | | Basic Size, mm | | Basic Size, mm | | Basic Size, mm | |
|-------------------|---------------|-------------------|---------------|-------------------|---------------|-------------------|---------------|
| 1st Choice | 2nd Choice | 1st Choice | 2nd Choice | 1st Choice | 2nd Choice | 1st Choice | 2nd Choice |
| 1 | ... | 6 | ... | 40 | ... | 250 | ... |
| ... | 1.1 | ... | 7 | ... | 45 | ... | 280 |
| 1.2 | ... | 8 | ... | 50 | ... | 300 | ... |
| ... | 1.4 | ... | 9 | ... | 55 | ... | 350 |
| 1.6 | ... | 10 | ... | 60 | ... | 400 | ... |
| ... | 1.8 | ... | 11 | ... | 70 | ... | 450 |
| 2 | ... | 12 | ... | 80 | ... | 500 | ... |
| ... | 2.2 | ... | 14 | ... | 90 | ... | 550 |
| 2.5 | ... | 16 | ... | 100 | ... | 600 | ... |
| ... | 2.8 | ... | 18 | ... | 110 | ... | 700 |
| 3 | ... | 20 | ... | 120 | ... | 800 | ... |
| ... | 3.5 | ... | 22 | ... | 140 | ... | 900 |
| 4 | ... | 25 | ... | 160 | ... | 1000 | ... |
| ... | 4.5 | ... | 28 | ... | 180 | ... | ... |
| 5 | ... | 30 | ... | 200 | ... | ... | ... |
| ... | 5.5 | ... | 35 | ... | 220 | ... | ... |

Preferred Fits.—First-choice tolerance zones are used to establish preferred fits in the Standard for Preferred Metric Limits and Fits, ANSI B4.2, as shown in Figs. 2 and 3. A complete listing of first-, second-, and third- choice tolerance zones is given in the Standard.

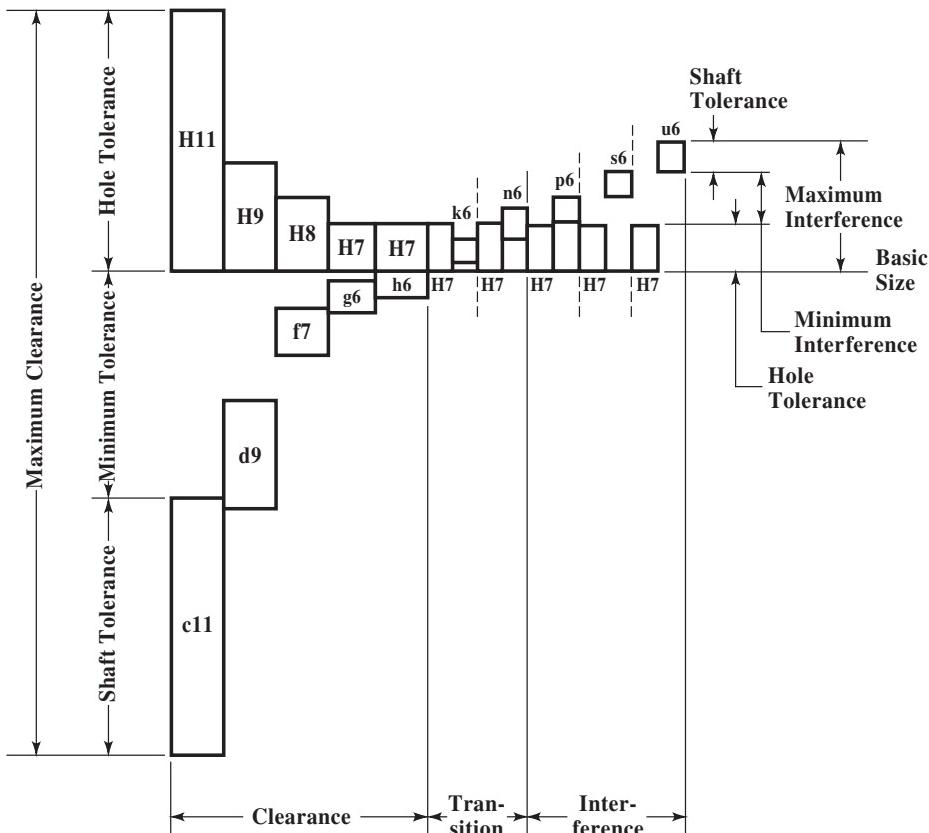


Fig. 2. Preferred Hole Basis Fits

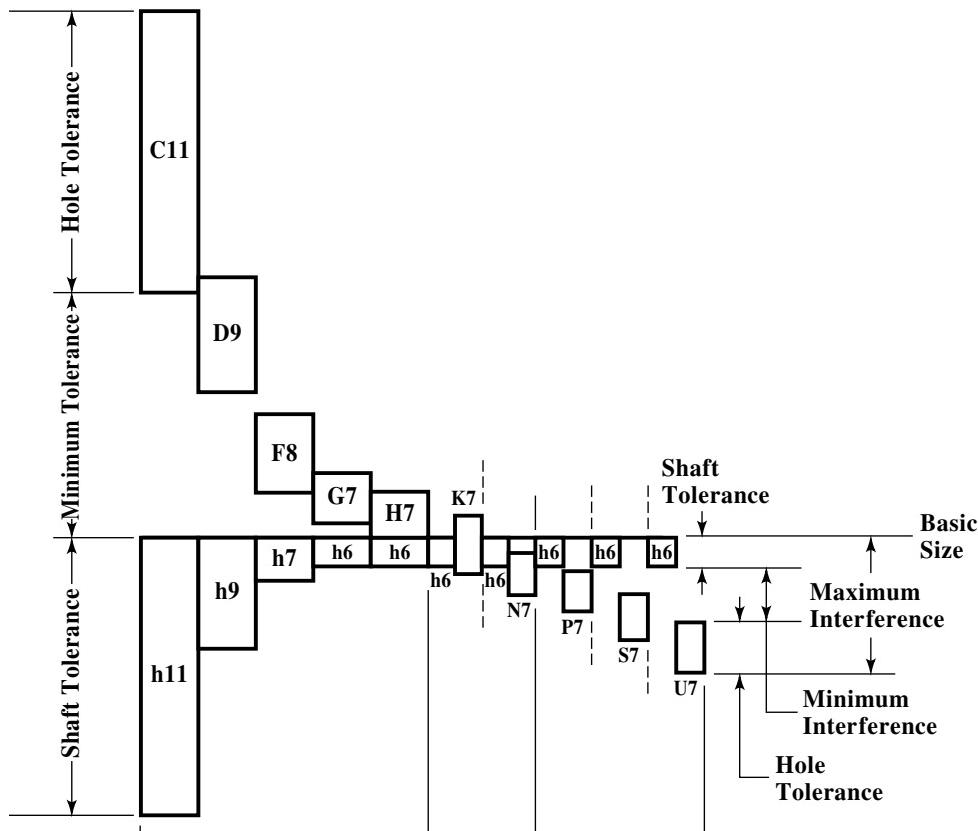


Fig. 3. Preferred Shaft Basis Fits

Hole basis fits have a fundamental deviation of H on the hole, and shaft basis fits have a fundamental deviation of h on the shaft and are shown in Fig. 2 for hole basis and Fig. 3 for shaft basis fits. A description of both types of fits, that have the same relative fit condition, is given in Table 13. Normally, the hole basis system is preferred; however, when a common shaft mates with several holes, the shaft basis system should be used.

The hole basis and shaft basis fits shown in Table 13 are combined with the first-choice sizes shown in Table 12 to form Tables 14, 15, 16, and 17, where specific limits as well as the resultant fits are tabulated.

If the required size is not tabulated in Tables 14 through 17, then the preferred fit can be calculated from numerical values given in an appendix of ANSI B4.2-1978 (R2004). It is anticipated that other fit conditions may be necessary to meet special requirements, and a preferred fit can be loosened or tightened simply by selecting a standard tolerance zone as given in the Standard. Information on how to calculate limit dimensions, clearances, and interferences, for nonpreferred fits and sizes can also be found in an appendix of this Standard.

By combining the IT grade number and the tolerance position letter, the tolerance symbol is established that identifies the actual maximum and minimum limits of the part. The tolerances size is thus defined by the basic size of the part followed by a symbol composed of a letter and a number, such as 40H7, 40f7, etc.

Table 13. Terms Used For Preferred Fits

| | ISO SYMBOL | | DESCRIPTION | |
|-------------------|--------------------|-------------|---|------------------------|
| | Hole Basis | Shaft Basis | | |
| Clearance Fits | H11/c11 | C11/h11 | <u>Loose running</u> fit for wide commercial tolerances or allowances on external members. | ↑ More Clearance |
| | H9/d9 | D9/h9 | <u>Free running</u> fit not for use where accuracy is essential, but good for large temperature variations, high running speeds, or heavy journal pressures. | |
| | H8/f7 | F8/h7 | <u>Close Running</u> fit for running on accurate machines and for accurate moderate speeds and journal pressures. | |
| | H7/g6 | G7/h6 | <u>Sliding fit</u> not intended to run freely, but to move and turn freely and locate accurately. | |
| | H7/h6 | H7/h6 | <u>Locational clearance</u> fit provides snug fit for locating stationary parts; but can be freely assembled and disassembled. | |
| Transition Fits | H7/k6 | K7/h6 | <u>Locational transition</u> fit for accurate location, a compromise between clearance and interference. | ↓ More Interference |
| | H7/n6 | N7/h6 | <u>Locational transition</u> fit for more accurate location where greater interference is permissible. | |
| Interference Fits | H7/p6 ^a | P7/h6 | <u>Locational interference</u> fit for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements. | |
| | H7/s6 | S7/h6 | <u>Medium drive</u> fit for ordinary steel parts or shrink fits on light sections; the tightest fit usable with cast iron. | |
| | H7/u6 | U7/h6 | <u>Force</u> fit suitable for parts that can be highly stressed or for shrink fits where the heavy pressing forces required are impractical. | |

^a Transition fit for basic sizes in range from 0 through 3 mm.

Table 14. American National Standard Preferred Hole Basis Metric Clearance Fits ANSI B4.2–1978, R2004

| Basic Size ^a | | Loose Running | | | Free Running | | | Close Running | | | Sliding | | | Locational Clearance | | |
|-------------------------|-----|---------------|-----------|------------------|--------------|----------|------------------|---------------|----------|------------------|---------|----------|------------------|----------------------|----------|------------------|
| | | Hole H11 | Shaft c11 | Fit ^b | Hole H9 | Shaft d9 | Fit ^b | Hole H8 | Shaft f7 | Fit ^b | Hole H7 | Shaft g6 | Fit ^b | Hole H7 | Shaft h6 | Fit ^b |
| 1 | Max | 1.060 | 0.940 | 0.180 | 1.025 | 0.980 | 0.070 | 1.014 | 0.994 | 0.030 | 1.010 | 0.998 | 0.018 | 1.010 | 1.000 | 0.016 |
| | Min | 1.000 | 0.880 | 0.060 | 1.000 | 0.995 | 0.020 | 1.000 | 0.984 | 0.006 | 1.000 | 0.992 | 0.002 | 1.000 | 0.994 | 0.000 |
| 1.2 | Max | 1.260 | 1.140 | 0.180 | 1.225 | 1.180 | 0.070 | 1.214 | 1.194 | 0.030 | 1.210 | 1.198 | 0.018 | 1.210 | 1.200 | 0.016 |
| | Min | 1.200 | 1.080 | 0.060 | 1.200 | 1.155 | 0.020 | 1.200 | 1.184 | 0.006 | 1.200 | 1.192 | 0.002 | 1.200 | 1.194 | 0.000 |
| 1.6 | Max | 1.660 | 1.540 | 0.180 | 1.625 | 1.580 | 0.070 | 1.614 | 1.594 | 0.030 | 1.610 | 1.598 | 0.018 | 1.610 | 1.600 | 0.016 |
| | Min | 1.600 | 1.480 | 0.060 | 1.600 | 1.555 | 0.020 | 1.600 | 1.584 | 0.006 | 1.600 | 1.592 | 0.002 | 1.600 | 1.594 | 0.000 |
| 2 | Max | 2.060 | 1.940 | 0.180 | 2.025 | 1.980 | 0.070 | 2.014 | 1.994 | 0.030 | 2.010 | 1.998 | 0.018 | 2.010 | 2.000 | 0.016 |
| | Min | 2.000 | 1.880 | 0.060 | 2.000 | 1.955 | 0.020 | 2.000 | 1.984 | 0.006 | 2.000 | 1.992 | 0.002 | 2.000 | 1.994 | 0.000 |
| 2.5 | Max | 2.560 | 2.440 | 0.180 | 2.525 | 2.480 | 0.070 | 2.514 | 2.494 | 0.030 | 2.510 | 2.498 | 0.018 | 2.510 | 2.500 | 0.016 |
| | Min | 2.500 | 2.380 | 0.060 | 2.500 | 2.455 | 0.020 | 2.500 | 2.484 | 0.006 | 2.500 | 2.492 | 0.002 | 2.500 | 2.494 | 0.000 |
| 3 | Max | 3.060 | 2.940 | 0.180 | 3.025 | 2.980 | 0.070 | 3.014 | 2.994 | 0.030 | 3.010 | 2.998 | 0.018 | 3.010 | 3.000 | 0.016 |
| | Min | 3.000 | 2.880 | 0.060 | 3.000 | 2.955 | 0.020 | 3.000 | 2.984 | 0.006 | 3.000 | 2.992 | 0.002 | 3.000 | 2.994 | 0.000 |
| 4 | Max | 4.075 | 3.930 | 0.220 | 4.030 | 3.970 | 0.090 | 4.018 | 3.990 | 0.040 | 4.012 | 3.996 | 0.024 | 4.012 | 4.000 | 0.020 |
| | Min | 4.000 | 3.855 | 0.070 | 4.000 | 3.940 | 0.030 | 4.000 | 3.978 | 0.010 | 4.000 | 3.988 | 0.004 | 4.000 | 3.992 | 0.000 |
| 5 | Max | 5.075 | 4.930 | 0.220 | 5.030 | 4.970 | 0.090 | 5.018 | 4.990 | 0.040 | 5.012 | 4.996 | 0.024 | 5.012 | 5.000 | 0.020 |
| | Min | 5.000 | 4.855 | 0.070 | 5.000 | 4.940 | 0.030 | 5.000 | 4.978 | 0.010 | 5.000 | 4.988 | 0.004 | 5.000 | 4.992 | 0.000 |
| 6 | Max | 6.075 | 5.930 | 0.220 | 6.030 | 5.970 | 0.090 | 6.018 | 5.990 | 0.040 | 6.012 | 5.996 | 0.024 | 6.012 | 6.000 | 0.020 |
| | Min | 6.000 | 5.855 | 0.070 | 6.000 | 5.940 | 0.030 | 6.000 | 5.978 | 0.010 | 6.000 | 5.988 | 0.004 | 6.000 | 5.992 | 0.000 |
| 8 | Max | 8.090 | 7.920 | 0.260 | 8.036 | 7.960 | 0.112 | 8.022 | 7.987 | 0.050 | 8.015 | 7.995 | 0.029 | 8.015 | 8.000 | 0.024 |
| | Min | 8.000 | 7.830 | 0.080 | 8.000 | 7.924 | 0.040 | 8.000 | 7.972 | 0.013 | 8.000 | 7.986 | 0.005 | 8.000 | 7.991 | 0.000 |
| 10 | Max | 10.090 | 9.920 | 0.260 | 10.036 | 9.960 | 0.112 | 10.022 | 9.987 | 0.050 | 10.015 | 9.995 | 0.029 | 10.015 | 10.000 | 0.024 |
| | Min | 10.000 | 9.830 | 0.080 | 10.000 | 9.924 | 0.040 | 10.000 | 9.972 | 0.013 | 10.000 | 9.986 | 0.005 | 10.000 | 9.991 | 0.000 |
| 12 | Max | 12.110 | 11.905 | 0.315 | 12.043 | 11.956 | 0.136 | 12.027 | 11.984 | 0.061 | 12.018 | 11.994 | 0.035 | 12.018 | 12.000 | 0.029 |
| | Min | 12.000 | 11.795 | 0.095 | 12.000 | 11.907 | 0.050 | 12.000 | 11.966 | 0.016 | 12.000 | 11.983 | 0.006 | 12.000 | 11.989 | 0.000 |
| 16 | Max | 16.110 | 15.905 | 0.315 | 16.043 | 15.950 | 0.136 | 16.027 | 15.984 | 0.061 | 16.018 | 15.994 | 0.035 | 16.018 | 16.000 | 0.029 |
| | Min | 16.000 | 15.795 | 0.095 | 16.000 | 15.907 | 0.050 | 16.000 | 15.966 | 0.016 | 16.000 | 15.983 | 0.006 | 16.000 | 15.989 | 0.000 |
| 20 | Max | 20.130 | 19.890 | 0.370 | 20.052 | 19.935 | 0.169 | 20.033 | 19.980 | 0.074 | 20.021 | 19.993 | 0.041 | 20.021 | 20.000 | 0.034 |
| | Min | 20.000 | 19.760 | 0.110 | 20.000 | 19.883 | 0.065 | 20.000 | 19.959 | 0.020 | 20.000 | 19.980 | 0.007 | 20.000 | 19.987 | 0.000 |
| 25 | Max | 25.130 | 24.890 | 0.370 | 25.052 | 24.935 | 0.169 | 25.033 | 24.980 | 0.074 | 25.021 | 24.993 | 0.041 | 25.021 | 25.000 | 0.034 |
| | Min | 25.000 | 24.760 | 0.110 | 25.000 | 24.883 | 0.065 | 25.000 | 24.959 | 0.020 | 25.000 | 24.980 | 0.007 | 25.000 | 24.987 | 0.000 |

Table 14.(Continued) American National Standard Preferred Hole Basis Metric Clearance Fits ANSI B4.2–1978, R2004

| Basic Size ^a | | Loose Running | | | Free Running | | | Close Running | | | Sliding | | | Locational Clearance | | |
|-------------------------|-----|---------------|-----------|------------------|--------------|----------|------------------|---------------|----------|------------------|---------|----------|------------------|----------------------|----------|------------------|
| | | Hole H11 | Shaft c11 | Fit ^b | Hole H9 | Shaft d9 | Fit ^b | Hole H8 | Shaft f7 | Fit ^b | Hole H7 | Shaft g6 | Fit ^b | Hole H7 | Shaft h6 | Fit ^b |
| 30 | Max | 30.130 | 29.890 | 0.370 | 30.052 | 29.935 | 0.169 | 30.033 | 29.980 | 0.074 | 30.021 | 29.993 | 0.041 | 30.021 | 30.000 | 0.034 |
| | Min | 30.000 | 29.760 | 0.110 | 30.000 | 29.883 | 0.065 | 30.000 | 29.959 | 0.020 | 30.000 | 29.980 | 0.007 | 30.000 | 29.987 | 0.000 |
| 40 | Max | 40.160 | 39.880 | 0.440 | 40.062 | 39.920 | 0.204 | 40.039 | 39.975 | 0.089 | 40.025 | 39.991 | 0.050 | 40.025 | 40.000 | 0.041 |
| | Min | 40.000 | 39.720 | 0.120 | 40.000 | 39.858 | 0.080 | 40.000 | 39.950 | 0.025 | 40.000 | 39.975 | 0.009 | 40.000 | 39.984 | 0.000 |
| 50 | Max | 50.160 | 49.870 | 0.450 | 50.062 | 49.920 | 0.204 | 50.039 | 49.975 | 0.089 | 50.025 | 49.991 | 0.050 | 50.025 | 50.000 | 0.041 |
| | Min | 50.000 | 49.710 | 0.130 | 50.000 | 49.858 | 0.080 | 50.000 | 49.950 | 0.025 | 50.000 | 49.975 | 0.009 | 50.000 | 49.984 | 0.000 |
| 60 | Max | 60.190 | 59.860 | 0.520 | 60.074 | 59.900 | 0.248 | 60.046 | 59.970 | 0.106 | 60.030 | 59.990 | 0.059 | 60.030 | 60.000 | 0.049 |
| | Min | 60.000 | 59.670 | 0.140 | 60.000 | 59.826 | 0.100 | 60.000 | 59.940 | 0.030 | 60.000 | 59.971 | 0.010 | 60.000 | 59.981 | 0.000 |
| 80 | Max | 80.190 | 79.850 | 0.530 | 80.074 | 79.900 | 0.248 | 80.046 | 79.970 | 0.106 | 80.030 | 79.990 | 0.059 | 80.030 | 80.000 | 0.049 |
| | Min | 80.000 | 79.660 | 0.150 | 80.000 | 79.826 | 0.100 | 80.000 | 79.940 | 0.030 | 80.000 | 79.971 | 0.010 | 80.000 | 79.981 | 0.000 |
| 100 | Max | 100.220 | 99.830 | 0.610 | 100.087 | 99.880 | 0.294 | 100.054 | 99.964 | 0.125 | 100.035 | 99.988 | 0.069 | 100.035 | 100.000 | 0.057 |
| | Min | 100.000 | 99.610 | 0.170 | 100.000 | 99.793 | 0.120 | 100.000 | 99.929 | 0.036 | 100.000 | 99.966 | 0.012 | 100.000 | 99.978 | 0.000 |
| 120 | Max | 120.220 | 119.820 | 0.620 | 120.087 | 119.880 | 0.294 | 120.054 | 119.964 | 0.125 | 120.035 | 119.988 | 0.069 | 120.035 | 120.000 | 0.057 |
| | Min | 120.000 | 119.600 | 0.180 | 120.000 | 119.793 | 0.120 | 120.000 | 119.929 | 0.036 | 120.000 | 119.966 | 0.012 | 120.000 | 119.978 | 0.000 |
| 160 | Max | 160.250 | 159.790 | 0.710 | 160.100 | 159.855 | 0.345 | 160.063 | 159.957 | 0.146 | 160.040 | 159.986 | 0.079 | 160.040 | 160.000 | 0.065 |
| | Min | 160.000 | 159.540 | 0.210 | 160.000 | 159.755 | 0.145 | 160.000 | 159.917 | 0.043 | 160.000 | 159.961 | 0.014 | 160.000 | 159.975 | 0.000 |
| 200 | Max | 200.290 | 199.760 | 0.820 | 200.115 | 199.830 | 0.400 | 200.072 | 199.950 | 0.168 | 200.046 | 199.985 | 0.090 | 200.046 | 200.000 | 0.075 |
| | Min | 200.000 | 199.470 | 0.240 | 200.000 | 199.715 | 0.170 | 200.000 | 199.904 | 0.050 | 200.000 | 199.956 | 0.015 | 200.000 | 199.971 | 0.000 |
| 250 | Max | 250.290 | 249.720 | 0.860 | 250.115 | 249.830 | 0.400 | 250.072 | 249.950 | 0.168 | 250.046 | 249.985 | 0.090 | 250.046 | 250.000 | 0.075 |
| | Min | 250.000 | 249.430 | 0.280 | 250.000 | 249.715 | 0.170 | 250.000 | 249.904 | 0.050 | 250.000 | 249.956 | 0.015 | 250.000 | 249.971 | 0.000 |
| 300 | Max | 300.320 | 299.670 | 0.970 | 300.130 | 299.810 | 0.450 | 300.081 | 299.944 | 0.189 | 300.052 | 299.983 | 0.101 | 300.052 | 300.000 | 0.084 |
| | Min | 300.000 | 299.350 | 0.330 | 300.000 | 299.680 | 0.190 | 300.000 | 299.892 | 0.056 | 300.000 | 299.951 | 0.017 | 300.000 | 299.968 | 0.000 |
| 400 | Max | 400.360 | 399.600 | 1.120 | 400.140 | 399.790 | 0.490 | 400.089 | 399.938 | 0.208 | 400.057 | 399.982 | 0.111 | 400.057 | 400.000 | 0.093 |
| | Min | 400.000 | 399.240 | 0.400 | 400.000 | 399.650 | 0.210 | 400.000 | 399.881 | 0.062 | 400.000 | 399.946 | 0.018 | 400.000 | 399.964 | 0.000 |
| 500 | Max | 500.400 | 499.520 | 1.280 | 500.155 | 499.770 | 0.540 | 500.097 | 499.932 | 0.228 | 500.063 | 499.980 | 0.123 | 500.063 | 500.000 | 0.103 |
| | Min | 500.000 | 499.120 | 0.480 | 500.000 | 499.615 | 0.230 | 500.000 | 499.869 | 0.068 | 500.000 | 499.940 | 0.020 | 500.000 | 499.960 | 0.000 |

^aThe sizes shown are first-choice basic sizes (see Table 12). Preferred fits for other sizes can be calculated from data given in ANSI B4.2–1978, R2004.

^bAll fits shown in this table have clearance.

All dimensions are in millimeters.

Table 15. American National Standard Preferred Hole Basis Metric Transition and Interference Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Locational Transition | | | Locational Transition | | | Locational Interference | | | Medium Drive | | | Force | | |
|-------------------------|-----|-----------------------|----------|------------------|-----------------------|----------|------------------|-------------------------|----------|------------------|--------------|----------|------------------|---------|----------|------------------|
| | | Hole H7 | Shaft k6 | Fit ^b | Hole H7 | Shaft n6 | Fit ^b | Hole H7 | Shaft p6 | Fit ^b | Hole H7 | Shaft s6 | Fit ^b | Hole H7 | Shaft u6 | Fit ^b |
| 1 | Max | 1.010 | 1.006 | +0.010 | 1.010 | 1.010 | +0.006 | 1.010 | 1.012 | +0.004 | 1.010 | 1.020 | -0.004 | 1.010 | 1.024 | -0.008 |
| | Min | 1.000 | 1.000 | -0.006 | 1.000 | 1.004 | -0.010 | 1.000 | 1.006 | -0.012 | 1.000 | 1.014 | -0.020 | 1.000 | 1.018 | -0.024 |
| 1.2 | Max | 1.210 | 1.206 | +0.010 | 1.210 | 1.210 | +0.006 | 1.210 | 1.212 | +0.004 | 1.210 | 1.220 | -0.004 | 1.210 | 1.224 | -0.008 |
| | Min | 1.200 | 1.200 | -0.006 | 1.200 | 1.204 | -0.010 | 1.200 | 1.206 | -0.012 | 1.200 | 1.214 | -0.020 | 1.200 | 1.218 | -0.024 |
| 1.6 | Max | 1.610 | 1.606 | +0.010 | 1.610 | 1.610 | +0.006 | 1.610 | 1.612 | +0.004 | 1.610 | 1.620 | -0.004 | 1.610 | 1.624 | -0.008 |
| | Min | 1.600 | 1.600 | -0.006 | 1.600 | 1.604 | -0.010 | 1.600 | 1.606 | -0.012 | 1.600 | 1.614 | -0.020 | 1.600 | 1.618 | -0.024 |
| 2 | Max | 2.010 | 2.006 | +0.010 | 2.010 | 2.010 | +0.006 | 2.010 | 2.012 | +0.004 | 2.010 | 2.020 | -0.004 | 2.010 | 2.024 | -0.008 |
| | Min | 2.000 | 2.000 | -0.006 | 2.000 | 2.004 | -0.010 | 2.000 | 2.006 | -0.012 | 2.000 | 2.014 | -0.020 | 2.000 | 2.018 | -0.024 |
| 2.5 | Max | 2.510 | 2.506 | +0.010 | 2.510 | 2.510 | +0.006 | 2.510 | 2.512 | +0.004 | 2.510 | 2.520 | -0.004 | 2.510 | 2.524 | -0.008 |
| | Min | 2.500 | 2.500 | -0.006 | 2.500 | 2.504 | -0.010 | 2.500 | 2.506 | -0.012 | 2.500 | 2.514 | -0.020 | 2.500 | 2.518 | -0.024 |
| 3 | Max | 3.010 | 3.006 | +0.010 | 3.010 | 3.010 | +0.006 | 3.010 | 3.012 | +0.004 | 3.010 | 3.020 | -0.004 | 3.010 | 3.024 | -0.008 |
| | Min | 3.000 | 3.000 | -0.006 | 3.000 | 3.004 | -0.010 | 3.000 | 3.006 | -0.012 | 3.000 | 3.014 | -0.020 | 3.000 | 3.018 | -0.024 |
| 4 | Max | 4.012 | 4.009 | +0.011 | 4.012 | 4.016 | +0.004 | 4.012 | 4.020 | 0.000 | 4.012 | 4.027 | -0.007 | 4.012 | 4.031 | -0.011 |
| | Min | 4.000 | 4.001 | -0.009 | 4.000 | 4.008 | -0.016 | 4.000 | 4.012 | -0.020 | 4.000 | 4.019 | -0.027 | 4.000 | 4.023 | -0.031 |
| 5 | Max | 5.012 | 5.009 | +0.011 | 5.012 | 5.016 | +0.004 | 5.012 | 5.020 | 0.000 | 5.012 | 5.027 | -0.007 | 5.012 | 5.031 | -0.011 |
| | Min | 5.000 | 5.001 | -0.009 | 5.000 | 5.008 | -0.016 | 5.000 | 5.012 | -0.020 | 5.000 | 5.019 | -0.027 | 5.000 | 5.023 | -0.031 |
| 6 | Max | 6.012 | 6.009 | +0.011 | 6.012 | 6.016 | +0.004 | 6.012 | 6.020 | 0.000 | 6.012 | 6.027 | -0.007 | 6.012 | 6.031 | -0.011 |
| | Min | 6.000 | 6.001 | -0.009 | 6.000 | 6.008 | -0.016 | 6.000 | 6.012 | -0.020 | 6.000 | 6.019 | -0.027 | 6.000 | 6.023 | -0.031 |
| 8 | Max | 8.015 | 8.010 | +0.014 | 8.015 | 8.019 | +0.005 | 8.015 | 8.024 | 0.000 | 8.015 | 8.032 | -0.008 | 8.015 | 8.037 | -0.013 |
| | Min | 8.000 | 8.001 | -0.010 | 8.000 | 8.010 | -0.019 | 8.000 | 8.015 | -0.024 | 8.000 | 8.023 | -0.032 | 8.000 | 8.028 | -0.037 |
| 10 | Max | 10.015 | 10.010 | +0.014 | 10.015 | 10.019 | +0.005 | 10.015 | 10.024 | 0.000 | 10.015 | 10.032 | -0.008 | 10.015 | 10.034 | -0.013 |
| | Min | 10.000 | 10.001 | -0.010 | 10.000 | 10.010 | -0.019 | 10.000 | 10.015 | -0.024 | 10.000 | 10.023 | -0.032 | 10.000 | 10.028 | -0.037 |
| 12 | Max | 12.018 | 12.012 | +0.017 | 12.018 | 12.023 | +0.006 | 12.018 | 12.029 | 0.000 | 12.018 | 12.039 | -0.010 | 12.018 | 12.044 | -0.015 |
| | Min | 12.000 | 12.001 | -0.012 | 12.000 | 12.012 | -0.023 | 12.000 | 12.018 | -0.029 | 12.000 | 12.028 | -0.039 | 12.000 | 12.033 | -0.044 |
| 16 | Max | 16.018 | 16.012 | +0.017 | 16.018 | 16.023 | +0.006 | 16.018 | 16.029 | 0.000 | 16.018 | 16.039 | -0.010 | 16.018 | 16.044 | -0.015 |
| | Min | 16.000 | 16.001 | -0.012 | 16.000 | 16.012 | -0.023 | 16.000 | 16.018 | -0.029 | 16.000 | 16.028 | -0.039 | 16.000 | 16.033 | -0.044 |
| 20 | Max | 20.021 | 20.015 | +0.019 | 20.021 | 20.028 | +0.006 | 20.021 | 20.035 | -0.001 | 20.021 | 20.048 | -0.014 | 20.021 | 20.054 | -0.020 |
| | Min | 20.000 | 20.002 | -0.015 | 20.000 | 20.015 | -0.028 | 20.000 | 20.022 | -0.035 | 20.000 | 20.035 | -0.048 | 20.000 | 20.041 | -0.054 |
| 25 | Max | 25.021 | 25.015 | +0.019 | 25.021 | 25.028 | +0.006 | 25.021 | 25.035 | -0.001 | 25.021 | 25.048 | -0.014 | 25.021 | 25.061 | -0.027 |
| | Min | 25.000 | 25.002 | -0.015 | 25.000 | 25.015 | -0.028 | 25.000 | 25.022 | -0.035 | 25.000 | 25.035 | -0.048 | 25.000 | 25.048 | -0.061 |

Table 15. (Continued) American National Standard Preferred Hole Basis Metric Transition and Interference Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Locational Transition | | | Locational Transition | | | Locational Interference | | | Medium Drive | | | Force | | |
|-------------------------|-----|-----------------------|----------|------------------|-----------------------|----------|------------------|-------------------------|----------|------------------|--------------|----------|------------------|---------|----------|------------------|
| | | Hole H7 | Shaft k6 | Fit ^b | Hole H7 | Shaft n6 | Fit ^b | Hole H7 | Shaft p6 | Fit ^b | Hole H7 | Shaft s6 | Fit ^b | Hole H7 | Shaft u6 | Fit ^b |
| 30 | Max | 30.021 | 30.015 | +0.019 | 30.021 | 30.028 | +0.006 | 30.021 | 30.035 | -0.001 | 30.021 | 30.048 | -0.014 | 30.021 | 30.061 | -0.027 |
| | Min | 30.000 | 30.002 | -0.015 | 30.000 | 30.015 | -0.028 | 30.000 | 30.022 | -0.035 | 30.000 | 30.035 | -0.048 | 30.000 | 30.048 | -0.061 |
| 40 | Max | 40.025 | 40.018 | +0.023 | 40.025 | 40.033 | +0.008 | 40.025 | 40.042 | -0.001 | 40.025 | 40.059 | -0.018 | 40.025 | 40.076 | -0.035 |
| | Min | 40.000 | 40.002 | -0.018 | 40.000 | 40.017 | -0.033 | 40.000 | 40.026 | -0.042 | 40.000 | 40.043 | -0.059 | 40.000 | 40.060 | -0.076 |
| 50 | Max | 50.025 | 50.018 | +0.023 | 50.025 | 50.033 | +0.008 | 50.025 | 50.042 | -0.001 | 50.025 | 50.059 | -0.018 | 50.025 | 50.086 | -0.045 |
| | Min | 50.000 | 50.002 | -0.018 | 50.000 | 50.017 | -0.033 | 50.000 | 50.026 | -0.042 | 50.000 | 50.043 | -0.059 | 50.000 | 50.070 | -0.086 |
| 60 | Max | 60.030 | 60.021 | +0.028 | 60.030 | 60.039 | +0.010 | 60.030 | 60.051 | -0.002 | 60.030 | 60.072 | -0.023 | 60.030 | 60.106 | -0.057 |
| | Min | 60.000 | 60.002 | -0.021 | 60.000 | 60.020 | -0.039 | 60.000 | 60.032 | -0.051 | 60.000 | 60.053 | -0.072 | 60.000 | 60.087 | -0.106 |
| 80 | Max | 80.030 | 80.021 | +0.028 | 80.030 | 80.039 | +0.010 | 80.030 | 80.051 | -0.002 | 80.030 | 80.078 | -0.029 | 80.030 | 80.121 | -0.072 |
| | Min | 80.000 | 80.002 | -0.021 | 80.000 | 80.020 | -0.039 | 80.000 | 80.032 | -0.051 | 80.000 | 80.059 | -0.078 | 80.000 | 80.102 | -0.121 |
| 100 | Max | 100.035 | 100.025 | +0.032 | 100.035 | 100.045 | +0.012 | 100.035 | 100.059 | -0.002 | 100.035 | 100.093 | -0.036 | 100.035 | 100.146 | -0.089 |
| | Min | 100.000 | 100.003 | -0.025 | 100.000 | 100.023 | -0.045 | 100.000 | 100.037 | -0.059 | 100.000 | 100.071 | -0.093 | 100.000 | 100.124 | -0.146 |
| 120 | Max | 120.035 | 120.025 | +0.032 | 120.035 | 120.045 | +0.012 | 120.035 | 120.059 | -0.002 | 120.035 | 120.101 | -0.044 | 120.035 | 120.166 | -0.109 |
| | Min | 120.000 | 120.003 | -0.025 | 120.000 | 120.023 | -0.045 | 120.000 | 120.037 | -0.059 | 120.000 | 120.079 | -0.101 | 120.000 | 120.144 | -0.166 |
| 160 | Max | 160.040 | 160.028 | +0.037 | 160.040 | 160.052 | +0.013 | 160.040 | 160.068 | -0.003 | 160.040 | 160.125 | -0.060 | 160.040 | 160.215 | -0.150 |
| | Min | 160.000 | 160.003 | -0.028 | 160.000 | 160.027 | -0.052 | 160.000 | 160.043 | -0.068 | 160.000 | 160.100 | -0.125 | 160.000 | 160.190 | -0.215 |
| 200 | Max | 200.046 | 200.033 | +0.042 | 200.046 | 200.060 | +0.015 | 200.046 | 200.079 | -0.004 | 200.046 | 200.151 | -0.076 | 200.046 | 200.265 | -0.190 |
| | Min | 200.000 | 200.004 | -0.033 | 200.000 | 200.031 | -0.060 | 200.000 | 200.050 | -0.079 | 200.000 | 200.122 | -0.151 | 200.000 | 200.236 | -0.265 |
| 250 | Max | 250.046 | 250.033 | +0.042 | 250.046 | 250.060 | +0.015 | 250.046 | 250.079 | -0.004 | 250.046 | 250.169 | -0.094 | 250.046 | 250.313 | -0.238 |
| | Min | 250.000 | 250.004 | -0.033 | 250.000 | 250.031 | -0.060 | 250.000 | 250.050 | -0.079 | 250.000 | 250.140 | -0.169 | 250.000 | 250.284 | -0.313 |
| 300 | Max | 300.052 | 300.036 | +0.048 | 300.052 | 300.066 | +0.018 | 300.052 | 300.088 | -0.004 | 300.052 | 300.202 | -0.118 | 300.052 | 300.382 | -0.298 |
| | Min | 300.000 | 300.004 | -0.036 | 300.000 | 300.034 | -0.066 | 300.000 | 300.056 | -0.088 | 300.000 | 300.170 | -0.202 | 300.000 | 300.350 | -0.382 |
| 400 | Max | 400.057 | 400.040 | +0.053 | 400.057 | 400.073 | +0.020 | 400.057 | 400.098 | -0.005 | 400.057 | 400.244 | -0.151 | 400.057 | 400.471 | -0.378 |
| | Min | 400.000 | 400.004 | -0.040 | 400.000 | 400.037 | -0.073 | 400.000 | 400.062 | -0.098 | 400.000 | 400.208 | -0.244 | 400.000 | 400.435 | -0.471 |
| 500 | Max | 500.063 | 500.045 | +0.058 | 500.063 | 500.080 | +0.023 | 500.063 | 500.108 | -0.005 | 500.063 | 500.292 | -0.189 | 500.063 | 500.580 | -0.477 |
| | Min | 500.000 | 500.005 | -0.045 | 500.000 | 500.040 | -0.080 | 500.000 | 500.068 | -0.108 | 500.000 | 500.252 | -0.292 | 500.000 | 500.540 | -0.580 |

^aThe sizes shown are first-choice basic sizes (see Table 12). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978, R2004.

^bA plus sign indicates clearance; a minus sign indicates interference.

All dimensions are in millimeters.

Table 16. American National Standard Preferred Shaft Basis Metric Clearance Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Loose Running | | | Free Running | | | Close Running | | | Sliding | | | Locational Clearance | | |
|-------------------------|-----|---------------|-----------|------------------|--------------|----------|------------------|---------------|----------|------------------|---------|----------|------------------|----------------------|----------|------------------|
| | | Hole C11 | Shaft h11 | Fit ^b | Hole D9 | Shaft h9 | Fit ^b | Hole F8 | Shaft h7 | Fit ^b | Hole G7 | Shaft h6 | Fit ^b | Hole H7 | Shaft h6 | Fit ^b |
| 1 | Max | 1.120 | 1.000 | 0.180 | 1.045 | 1.000 | 0.070 | 1.020 | 1.000 | 0.030 | 1.012 | 1.000 | 0.018 | 1.010 | 1.000 | 0.016 |
| | Min | 1.060 | 0.940 | 0.060 | 1.020 | 0.975 | 0.020 | 1.006 | 0.990 | 0.006 | 1.002 | 0.994 | 0.002 | 1.000 | 0.994 | 0.000 |
| 1.2 | Max | 1.320 | 1.200 | 0.180 | 1.245 | 1.200 | 0.070 | 1.220 | 1.200 | 0.030 | 1.212 | 1.200 | 0.018 | 1.210 | 1.200 | 0.016 |
| | Min | 1.260 | 1.140 | 0.060 | 1.220 | 1.175 | 0.020 | 1.206 | 1.190 | 0.006 | 1.202 | 1.194 | 0.002 | 1.200 | 1.194 | 0.000 |
| 1.6 | Max | 1.720 | 1.600 | 0.180 | 1.645 | 1.600 | 0.070 | 1.620 | 1.600 | 0.030 | 1.612 | 1.600 | 0.018 | 1.610 | 1.600 | 0.016 |
| | Min | 1.660 | 1.540 | 0.060 | 1.620 | 1.575 | 0.020 | 1.606 | 1.590 | 0.006 | 1.602 | 1.594 | 0.002 | 1.600 | 1.594 | 0.000 |
| 2 | Max | 2.120 | 2.000 | 0.180 | 2.045 | 2.000 | 0.070 | 2.020 | 2.000 | 0.030 | 2.012 | 2.000 | 0.018 | 2.010 | 2.000 | 0.016 |
| | Min | 2.060 | 1.940 | 0.060 | 2.020 | 1.975 | 0.020 | 2.006 | 1.990 | 0.006 | 2.002 | 1.994 | 0.002 | 2.000 | 1.994 | 0.000 |
| 2.5 | Max | 2.620 | 2.500 | 0.180 | 2.545 | 2.500 | 0.070 | 2.520 | 2.500 | 0.030 | 2.512 | 2.500 | 0.018 | 2.510 | 2.500 | 0.016 |
| | Min | 2.560 | 2.440 | 0.060 | 2.520 | 2.475 | 0.020 | 2.506 | 2.490 | 0.006 | 2.502 | 2.494 | 0.002 | 2.500 | 2.494 | 0.000 |
| 3 | Max | 3.120 | 3.000 | 0.180 | 3.045 | 3.000 | 0.070 | 3.020 | 3.000 | 0.030 | 3.012 | 3.000 | 0.018 | 3.010 | 3.000 | 0.016 |
| | Min | 3.060 | 2.940 | 0.060 | 3.020 | 2.975 | 0.020 | 3.006 | 2.990 | 0.006 | 3.002 | 2.994 | 0.002 | 3.000 | 2.994 | 0.000 |
| 4 | Max | 4.145 | 4.000 | 0.220 | 4.060 | 4.000 | 0.090 | 4.028 | 4.000 | 0.040 | 4.016 | 4.000 | 0.024 | 4.012 | 4.000 | 0.020 |
| | Min | 4.070 | 3.925 | 0.070 | 4.030 | 3.970 | 0.030 | 4.010 | 3.988 | 0.010 | 4.004 | 3.992 | 0.004 | 4.000 | 3.992 | 0.000 |
| 5 | Max | 5.145 | 5.000 | 0.220 | 5.060 | 5.000 | 0.090 | 5.028 | 5.000 | 0.040 | 5.016 | 5.000 | 0.024 | 5.012 | 5.000 | 0.020 |
| | Min | 5.070 | 4.925 | 0.070 | 5.030 | 4.970 | 0.030 | 5.010 | 4.988 | 0.010 | 5.004 | 4.992 | 0.004 | 5.000 | 4.992 | 0.000 |
| 6 | Max | 6.145 | 6.000 | 0.220 | 6.060 | 6.000 | 0.090 | 6.028 | 6.000 | 0.040 | 6.016 | 6.000 | 0.024 | 6.012 | 6.000 | 0.020 |
| | Min | 6.070 | 5.925 | 0.070 | 6.030 | 5.970 | 0.030 | 6.010 | 5.988 | 0.010 | 6.004 | 5.992 | 0.004 | 6.000 | 5.992 | 0.000 |
| 8 | Max | 8.170 | 8.000 | 0.260 | 8.076 | 8.000 | 0.112 | 8.035 | 8.000 | 0.050 | 8.020 | 8.000 | 0.029 | 8.015 | 8.000 | 0.024 |
| | Min | 8.080 | 7.910 | 0.080 | 8.040 | 7.964 | 0.040 | 8.013 | 7.985 | 0.013 | 8.005 | 7.991 | 0.005 | 8.000 | 7.991 | 0.000 |
| 10 | Max | 10.170 | 10.000 | 0.260 | 10.076 | 10.000 | 0.112 | 10.035 | 10.000 | 0.050 | 10.020 | 10.000 | 0.029 | 10.015 | 10.000 | 0.024 |
| | Min | 10.080 | 9.910 | 0.080 | 10.040 | 9.964 | 0.040 | 10.013 | 9.985 | 0.013 | 10.005 | 9.991 | 0.005 | 10.000 | 9.991 | 0.000 |
| 12 | Max | 12.205 | 12.000 | 0.315 | 12.093 | 12.000 | 0.136 | 12.043 | 12.000 | 0.061 | 12.024 | 12.000 | 0.035 | 12.018 | 12.000 | 0.029 |
| | Min | 12.095 | 11.890 | 0.095 | 12.050 | 11.957 | 0.050 | 12.016 | 11.982 | 0.016 | 12.006 | 11.989 | 0.006 | 12.000 | 11.989 | 0.000 |
| 16 | Max | 16.205 | 16.000 | 0.315 | 16.093 | 16.000 | 0.136 | 16.043 | 16.000 | 0.061 | 16.024 | 16.000 | 0.035 | 16.018 | 16.000 | 0.029 |
| | Min | 16.095 | 15.890 | 0.095 | 16.050 | 15.957 | 0.050 | 16.016 | 15.982 | 0.016 | 16.006 | 15.989 | 0.006 | 16.000 | 15.989 | 0.000 |
| 20 | Max | 20.240 | 20.000 | 0.370 | 20.117 | 20.000 | 0.169 | 20.053 | 20.000 | 0.074 | 20.028 | 20.000 | 0.041 | 20.021 | 20.000 | 0.034 |
| | Min | 20.110 | 19.870 | 0.110 | 20.065 | 19.948 | 0.065 | 20.020 | 19.979 | 0.020 | 20.007 | 19.987 | 0.007 | 20.000 | 19.987 | 0.000 |
| 25 | Max | 25.240 | 25.000 | 0.370 | 25.117 | 25.000 | 0.169 | 25.053 | 25.000 | 0.074 | 25.028 | 25.000 | 0.041 | 25.021 | 25.000 | 0.034 |
| 25 | Min | 25.110 | 24.870 | 0.110 | 25.065 | 24.948 | 0.065 | 25.020 | 24.979 | 0.020 | 25.007 | 24.987 | 0.007 | 25.000 | 24.987 | 0.000 |

Table 16. (Continued) American National Standard Preferred Shaft Basis Metric Clearance Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Loose Running | | | Free Running | | | Close Running | | | Sliding | | | Locational Clearance | | |
|-------------------------|-----|---------------|-----------|------------------|--------------|----------|------------------|---------------|----------|------------------|---------|----------|------------------|----------------------|----------|------------------|
| | | Hole C11 | Shaft h11 | Fit ^b | Hole D9 | Shaft h9 | Fit ^b | Hole F8 | Shaft h7 | Fit ^b | Hole G7 | Shaft h6 | Fit ^b | Hole H7 | Shaft h6 | Fit ^b |
| 30 | Max | 30.240 | 30.000 | 0.370 | 30.117 | 30.000 | 0.169 | 30.053 | 30.000 | 0.074 | 30.028 | 30.000 | 0.041 | 30.021 | 30.000 | 0.034 |
| | Min | 30.110 | 29.870 | 0.110 | 30.065 | 29.948 | 0.065 | 30.020 | 29.979 | 0.020 | 30.007 | 29.987 | 0.007 | 30.000 | 29.987 | 0.000 |
| 40 | Max | 40.280 | 40.000 | 0.440 | 40.142 | 40.000 | 0.204 | 40.064 | 40.000 | 0.089 | 40.034 | 40.000 | 0.050 | 40.025 | 40.000 | 0.041 |
| | Min | 40.120 | 39.840 | 0.120 | 40.080 | 39.938 | 0.080 | 40.025 | 39.975 | 0.025 | 40.009 | 39.984 | 0.009 | 40.000 | 39.984 | 0.000 |
| 50 | Max | 50.290 | 50.000 | 0.450 | 50.142 | 50.000 | 0.204 | 50.064 | 50.000 | 0.089 | 50.034 | 50.000 | 0.050 | 50.025 | 50.000 | 0.041 |
| | Min | 50.130 | 49.840 | 0.130 | 50.080 | 49.938 | 0.080 | 50.025 | 49.975 | 0.025 | 50.009 | 49.984 | 0.009 | 50.000 | 49.984 | 0.000 |
| 60 | Max | 60.330 | 60.000 | 0.520 | 60.174 | 60.000 | 0.248 | 60.076 | 60.000 | 0.106 | 60.040 | 60.000 | 0.059 | 60.030 | 60.000 | 0.049 |
| | Min | 60.140 | 59.810 | 0.140 | 60.100 | 59.926 | 0.100 | 60.030 | 59.970 | 0.030 | 60.010 | 59.981 | 0.010 | 60.000 | 59.981 | 0.000 |
| 80 | Max | 80.340 | 80.000 | 0.530 | 80.174 | 80.000 | 0.248 | 80.076 | 80.000 | 0.106 | 80.040 | 80.000 | 0.059 | 80.030 | 80.000 | 0.049 |
| | Min | 80.150 | 79.810 | 0.150 | 80.100 | 79.926 | 0.100 | 80.030 | 79.970 | 0.030 | 80.010 | 79.981 | 0.010 | 80.000 | 79.981 | 0.000 |
| 100 | Max | 100.390 | 100.000 | 0.610 | 100.207 | 100.000 | 0.294 | 100.090 | 100.000 | 0.125 | 100.047 | 100.000 | 0.069 | 100.035 | 100.000 | 0.057 |
| | Min | 100.170 | 99.780 | 0.170 | 100.120 | 99.913 | 0.120 | 100.036 | 99.965 | 0.036 | 100.012 | 99.978 | 0.012 | 100.000 | 99.978 | 0.000 |
| 120 | Max | 120.400 | 120.000 | 0.620 | 120.207 | 120.000 | 0.294 | 120.090 | 120.000 | 0.125 | 120.047 | 120.000 | 0.069 | 120.035 | 120.000 | 0.057 |
| | Min | 120.180 | 119.780 | 0.180 | 120.120 | 119.913 | 0.120 | 120.036 | 119.965 | 0.036 | 120.012 | 119.978 | 0.012 | 120.000 | 119.978 | 0.000 |
| 160 | Max | 160.460 | 160.000 | 0.710 | 160.245 | 160.000 | 0.345 | 160.106 | 160.000 | 0.146 | 160.054 | 160.000 | 0.079 | 160.040 | 160.000 | 0.065 |
| | Min | 160.210 | 159.750 | 0.210 | 160.145 | 159.900 | 0.145 | 160.043 | 159.960 | 0.043 | 160.014 | 159.975 | 0.014 | 160.000 | 159.975 | 0.000 |
| 200 | Max | 200.530 | 200.000 | 0.820 | 200.285 | 200.000 | 0.400 | 200.122 | 200.000 | 0.168 | 200.061 | 200.000 | 0.090 | 200.046 | 200.000 | 0.075 |
| | Min | 200.240 | 199.710 | 0.240 | 200.170 | 199.885 | 0.170 | 200.050 | 199.954 | 0.050 | 200.015 | 199.971 | 0.015 | 200.000 | 199.971 | 0.000 |
| 250 | Max | 250.570 | 250.000 | 0.860 | 250.285 | 250.000 | 0.400 | 250.122 | 250.000 | 0.168 | 250.061 | 250.000 | 0.090 | 250.046 | 250.000 | 0.075 |
| | Min | 250.280 | 249.710 | 0.280 | 250.170 | 249.885 | 0.170 | 250.050 | 249.954 | 0.050 | 250.015 | 249.971 | 0.015 | 250.000 | 249.971 | 0.000 |
| 300 | Max | 300.650 | 300.000 | 0.970 | 300.320 | 300.000 | 0.450 | 300.137 | 300.000 | 0.189 | 300.069 | 300.000 | 0.101 | 300.052 | 300.000 | 0.084 |
| | Min | 300.330 | 299.680 | 0.330 | 300.190 | 299.870 | 0.190 | 300.056 | 299.948 | 0.056 | 300.017 | 299.968 | 0.017 | 300.000 | 299.968 | 0.000 |
| 400 | Max | 400.760 | 400.000 | 1.120 | 400.350 | 400.000 | 0.490 | 400.151 | 400.000 | 0.208 | 400.075 | 400.000 | 0.111 | 400.057 | 400.000 | 0.093 |
| | Min | 400.400 | 399.640 | 0.400 | 400.210 | 399.860 | 0.210 | 400.062 | 399.943 | 0.062 | 400.018 | 399.964 | 0.018 | 400.000 | 399.964 | 0.000 |
| 500 | Max | 500.880 | 500.000 | 1.280 | 500.385 | 500.000 | 0.540 | 500.165 | 500.000 | 0.228 | 500.083 | 500.000 | 0.123 | 500.063 | 500.000 | 0.103 |
| | Min | 500.480 | 499.600 | 0.480 | 500.230 | 499.845 | 0.230 | 500.068 | 499.937 | 0.068 | 500.020 | 499.960 | 0.020 | 500.000 | 499.960 | 0.000 |

^aThe sizes shown are first-choice basic sizes (see Table 12). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978, R2004.

^bAll fits shown in this table have clearance.

All dimensions are in millimeters.

Table 17. American National Standard Preferred Shaft Basis Metric Transition and Interference Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Locational Transition | | | Locational Transition | | | Locational Interference | | | Medium Drive | | | Force | | |
|-------------------------|-----|-----------------------|----------|------------------|-----------------------|----------|------------------|-------------------------|----------|------------------|--------------|----------|------------------|---------|----------|------------------|
| | | Hole K7 | Shaft h6 | Fit ^b | Hole N7 | Shaft h6 | Fit ^b | Hole P7 | Shaft h6 | Fit ^b | Hole S7 | Shaft h6 | Fit ^b | Hole U7 | Shaft h6 | Fit ^b |
| 1 | Max | 1.000 | 1.000 | +0.006 | 0.996 | 1.000 | +0.002 | 0.994 | 1.000 | 0.000 | 0.986 | 1.000 | -0.008 | 0.982 | 1.000 | -0.012 |
| | Min | 0.990 | 0.994 | -0.010 | 0.986 | 0.954 | -0.014 | 0.984 | 0.994 | -0.016 | 0.976 | 0.994 | -0.024 | 0.972 | 0.994 | -0.028 |
| 1.2 | Max | 1.200 | 1.200 | +0.006 | 1.196 | 1.200 | +0.002 | 1.194 | 1.200 | 0.000 | 1.186 | 1.200 | -0.008 | 1.182 | 1.200 | -0.012 |
| | Min | 1.190 | 1.194 | -0.010 | 1.186 | 1.194 | -0.014 | 1.184 | 1.194 | -0.016 | 1.176 | 1.194 | -0.024 | 1.172 | 1.194 | -0.028 |
| 1.6 | Max | 1.600 | 1.600 | +0.006 | 1.596 | 1.600 | +0.002 | 1.594 | 1.600 | 0.000 | 1.586 | 1.600 | -0.008 | 1.582 | 1.600 | -0.012 |
| | Min | 1.590 | 1.594 | -0.010 | 1.586 | 1.594 | -0.014 | 1.584 | 1.594 | -0.016 | 1.576 | 1.594 | -0.024 | 1.572 | 1.594 | -0.028 |
| 2 | Max | 2.000 | 2.000 | +0.006 | 1.996 | 2.000 | +0.002 | 1.994 | 2.000 | 0.000 | 1.986 | 2.000 | -0.008 | 1.982 | 2.000 | -0.012 |
| | Min | 1.990 | 1.994 | -0.010 | 1.986 | 1.994 | -0.014 | 1.984 | 1.994 | -0.016 | 1.976 | 1.994 | -0.024 | 1.972 | 1.994 | -0.028 |
| 2.5 | Max | 2.500 | 2.500 | +0.006 | 2.496 | 2.500 | +0.002 | 2.494 | 2.500 | 0.000 | 2.486 | 2.500 | -0.008 | 2.482 | 2.500 | -0.012 |
| | Min | 2.490 | 2.494 | -0.010 | 2.486 | 2.494 | -0.014 | 2.484 | 2.494 | -0.016 | 2.476 | 2.494 | -0.024 | 2.472 | 2.494 | -0.028 |
| 3 | Max | 3.000 | 3.000 | +0.006 | 2.996 | 3.000 | +0.002 | 2.994 | 3.000 | 0.000 | 2.986 | 3.000 | -0.008 | 2.982 | 3.000 | -0.012 |
| | Min | 2.990 | 2.994 | -0.010 | 2.986 | 2.994 | -0.014 | 2.984 | 2.994 | -0.016 | 2.976 | 2.994 | -0.024 | 2.972 | 2.994 | -0.028 |
| 4 | Max | 4.003 | 4.000 | +0.011 | 3.996 | 4.000 | +0.004 | 3.992 | 4.000 | 0.000 | 3.985 | 4.000 | -0.007 | 3.981 | 4.000 | -0.011 |
| | Min | 3.991 | 3.992 | -0.009 | 3.984 | 3.992 | -0.016 | 3.980 | 3.992 | -0.020 | 3.973 | 3.992 | -0.027 | 3.969 | 3.992 | -0.031 |
| 5 | Max | 5.003 | 5.000 | +0.011 | 4.996 | 5.000 | +0.004 | 4.992 | 5.000 | 0.000 | 4.985 | 5.000 | -0.007 | 4.981 | 5.000 | -0.011 |
| | Min | 4.991 | 4.992 | -0.009 | 4.984 | 4.992 | -0.016 | 4.980 | 4.992 | -0.020 | 4.973 | 4.992 | -0.027 | 4.969 | 4.992 | -0.031 |
| 6 | Max | 6.003 | 6.000 | +0.011 | 5.996 | 6.000 | +0.004 | 5.992 | 6.000 | 0.000 | 5.985 | 6.000 | -0.007 | 5.981 | 6.000 | -0.011 |
| | Min | 5.991 | 5.992 | -0.009 | 5.984 | 5.992 | -0.016 | 5.980 | 5.992 | -0.020 | 5.973 | 5.992 | -0.027 | 5.969 | 5.992 | -0.031 |
| 8 | Max | 8.005 | 8.000 | +0.014 | 7.996 | 8.000 | +0.005 | 7.991 | 8.000 | 0.000 | 7.983 | 8.000 | -0.008 | 7.978 | 8.000 | -0.013 |
| | Min | 7.990 | 7.991 | -0.010 | 7.981 | 7.991 | -0.019 | 7.976 | 7.991 | -0.024 | 7.968 | 7.991 | -0.032 | 7.963 | 7.991 | -0.037 |
| 10 | Max | 10.005 | 10.000 | +0.014 | 9.996 | 10.000 | +0.005 | 9.991 | 10.000 | 0.000 | 9.983 | 10.000 | -0.008 | 9.978 | 10.000 | -0.013 |
| | Min | 9.990 | 9.991 | -0.010 | 9.981 | 9.991 | -0.019 | 9.976 | 9.991 | -0.024 | 9.968 | 9.991 | -0.032 | 9.963 | 9.991 | -0.037 |
| 12 | Max | 12.006 | 12.000 | +0.017 | 11.995 | 12.000 | +0.006 | 11.989 | 12.000 | 0.000 | 11.979 | 12.000 | -0.010 | 11.974 | 12.000 | -0.015 |
| | Min | 11.988 | 11.989 | -0.012 | 11.977 | 11.989 | -0.023 | 11.971 | 11.989 | -0.029 | 11.961 | 11.989 | -0.039 | 11.956 | 11.989 | -0.044 |
| 16 | Max | 16.006 | 16.000 | +0.017 | 15.995 | 16.000 | +0.006 | 15.989 | 16.000 | 0.000 | 15.979 | 16.000 | -0.010 | 15.974 | 16.000 | -0.015 |
| | Min | 15.988 | 15.989 | -0.012 | 15.977 | 15.989 | -0.023 | 15.971 | 15.989 | -0.029 | 15.961 | 15.989 | -0.039 | 15.956 | 15.989 | -0.044 |
| 20 | Max | 20.006 | 20.000 | +0.019 | 19.993 | 20.000 | +0.006 | 19.986 | 20.000 | -0.001 | 19.973 | 20.000 | -0.014 | 19.967 | 20.000 | -0.020 |
| | Min | 19.985 | 19.987 | -0.015 | 19.972 | 19.987 | -0.028 | 19.965 | 19.987 | -0.035 | 19.952 | 19.987 | -0.048 | 19.946 | 19.987 | -0.054 |
| 25 | Max | 25.006 | 25.000 | +0.019 | 24.993 | 25.000 | +0.006 | 24.986 | 25.000 | -0.001 | 24.973 | 25.000 | -0.014 | 24.960 | 25.000 | -0.027 |
| | Min | 24.985 | 24.987 | -0.015 | 24.972 | 24.987 | -0.028 | 24.965 | 24.987 | -0.035 | 24.952 | 24.987 | -0.048 | 24.939 | 24.987 | -0.061 |

Table 17.(Continued) American National Standard Preferred Shaft Basis Metric Transition and Interference Fits ANSI B4.2-1978, R2004

| Basic Size ^a | | Locational Transition | | | Locational Transition | | | Locational Interference | | | Medium Drive | | | Force | | |
|-------------------------|-----|-----------------------|----------|------------------|-----------------------|----------|------------------|-------------------------|----------|------------------|--------------|----------|------------------|---------|----------|------------------|
| | | Hole K7 | Shaft h6 | Fit ^b | Hole N7 | Shaft h6 | Fit ^b | Hole P7 | Shaft h6 | Fit ^b | Hole S7 | Shaft h6 | Fit ^b | Hole U7 | Shaft h6 | Fit ^b |
| 30 | Max | 30.006 | 30.000 | +0.019 | 29.993 | 30.000 | +0.006 | 29.986 | 30.000 | -0.001 | 29.973 | 30.000 | -0.014 | 29.960 | 30.000 | -0.027 |
| | Min | 29.985 | 29.987 | -0.015 | 29.972 | 29.987 | -0.028 | 29.965 | 29.987 | -0.035 | 29.952 | 29.987 | -0.048 | 29.939 | 29.987 | -0.061 |
| 40 | Max | 40.007 | 40.000 | +0.023 | 39.992 | 40.000 | +0.008 | 39.983 | 40.000 | -0.001 | 39.966 | 40.000 | -0.018 | 39.949 | 40.000 | -0.035 |
| | Min | 39.982 | 39.984 | -0.018 | 39.967 | 39.984 | -0.033 | 39.958 | 39.984 | -0.042 | 39.941 | 39.984 | -0.059 | 39.924 | 39.984 | -0.076 |
| 50 | Max | 50.007 | 50.000 | +0.023 | 49.992 | 50.000 | +0.008 | 49.983 | 50.000 | -0.001 | 49.966 | 50.000 | -0.018 | 49.939 | 50.000 | -0.045 |
| | Min | 49.982 | 49.984 | -0.018 | 49.967 | 49.984 | -0.033 | 49.958 | 49.984 | -0.042 | 49.941 | 49.984 | -0.059 | 49.914 | 49.984 | -0.086 |
| 60 | Max | 60.009 | 60.000 | +0.028 | 59.991 | 60.000 | +0.010 | 59.979 | 60.000 | -0.002 | 59.958 | 60.000 | -0.023 | 59.924 | 60.000 | -0.087 |
| | Min | 59.979 | 59.981 | -0.021 | 59.961 | 59.981 | -0.039 | 59.949 | 59.981 | -0.051 | 59.928 | 59.981 | -0.072 | 59.894 | 59.981 | -0.106 |
| 80 | Max | 80.009 | 80.000 | +0.028 | 79.991 | 80.000 | +0.010 | 79.979 | 80.000 | -0.002 | 79.952 | 80.000 | -0.029 | 79.909 | 80.000 | -0.072 |
| | Min | 79.979 | 79.981 | -0.021 | 79.961 | 79.981 | -0.039 | 79.949 | 79.981 | -0.051 | 79.922 | 79.981 | -0.078 | 79.879 | 79.981 | -0.121 |
| 100 | Max | 100.010 | 100.000 | +0.032 | 99.990 | 100.000 | +0.012 | 99.976 | 100.000 | -0.002 | 99.942 | 100.000 | -0.036 | 99.889 | 100.000 | -0.089 |
| | Min | 99.975 | 99.978 | -0.025 | 99.955 | 99.978 | -0.045 | 99.941 | 99.978 | -0.059 | 99.907 | 99.978 | -0.093 | 99.854 | 99.978 | -0.146 |
| 120 | Max | 120.010 | 120.000 | +0.032 | 119.990 | 120.000 | +0.012 | 119.976 | 120.000 | -0.002 | 119.934 | 120.000 | -0.044 | 119.869 | 120.000 | -0.109 |
| | Min | 119.975 | 119.978 | -0.025 | 119.955 | 119.978 | -0.045 | 119.941 | 119.978 | -0.059 | 119.899 | 119.978 | -0.101 | 119.834 | 119.978 | -0.166 |
| 160 | Max | 160.012 | 160.000 | +0.037 | 159.988 | 160.000 | +0.013 | 159.972 | 160.000 | -0.003 | 159.915 | 160.000 | -0.060 | 159.825 | 160.000 | -0.150 |
| | Min | 159.972 | 159.975 | -0.028 | 159.948 | 159.975 | -0.052 | 159.932 | 159.975 | -0.068 | 159.875 | 159.975 | -0.125 | 159.785 | 159.975 | -0.215 |
| 200 | Max | 200.013 | 200.000 | +0.042 | 199.986 | 200.000 | +0.015 | 199.967 | 200.000 | -0.004 | 199.895 | 200.000 | -0.076 | 199.781 | 200.000 | -0.190 |
| | Min | 199.967 | 199.971 | -0.033 | 199.940 | 199.971 | -0.060 | 199.921 | 199.971 | -0.079 | 199.849 | 199.971 | -0.151 | 199.735 | 199.971 | -0.265 |
| 250 | Max | 250.013 | 250.000 | +0.042 | 249.986 | 250.000 | +0.015 | 249.967 | 250.000 | -0.004 | 249.877 | 250.000 | -0.094 | 249.733 | 250.000 | -0.238 |
| | Min | 249.967 | 249.971 | -0.033 | 249.940 | 249.971 | -0.060 | 249.921 | 249.971 | -0.079 | 249.831 | 249.971 | -0.169 | 249.687 | 249.971 | -0.313 |
| 300 | Max | 300.016 | 300.000 | +0.048 | 299.986 | 300.000 | +0.018 | 299.964 | 300.000 | -0.004 | 299.850 | 300.000 | -0.118 | 299.670 | 300.000 | -0.298 |
| | Min | 299.964 | 299.968 | -0.036 | 299.934 | 299.968 | -0.066 | 299.912 | 299.968 | -0.088 | 299.798 | 299.968 | -0.202 | 299.618 | 299.968 | -0.382 |
| 400 | Max | 400.017 | 400.000 | +0.053 | 399.984 | 400.000 | +0.020 | 399.959 | 400.000 | -0.005 | 399.813 | 400.000 | -0.151 | 399.586 | 400.000 | -0.378 |
| | Min | 399.960 | 399.964 | -0.040 | 399.927 | 399.964 | -0.073 | 399.902 | 399.964 | -0.098 | 399.756 | 399.964 | -0.244 | 399.529 | 399.964 | -0.471 |
| 500 | Max | 500.018 | 500.000 | +0.058 | 499.983 | 500.000 | +0.023 | 499.955 | 500.000 | -0.005 | 499.771 | 500.000 | -0.189 | 499.483 | 500.000 | -0.477 |
| | Min | 499.955 | 499.960 | -0.045 | 499.920 | 499.960 | -0.080 | 499.892 | 499.960 | -0.108 | 499.708 | 499.960 | -0.292 | 499.420 | 499.960 | -0.580 |

^aThe sizes shown are first-choice basic sizes (see Table 12). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978, R2004.

^bA plus sign indicates clearance; a minus sign indicates interference.

All dimensions are in millimeters.

**Table 18. American National Standard Gagemakers Tolerances
ANSI B4.4M-1981, R1994**

| Gagemakers Tolerance | | | Workpiece Tolerance | |
|--|-------------------------|-----------|------------------------|---|
| Class | ISO Symbol ^a | IT Grade | Recommended Gage Usage | |
| ↑ Rejection of Good Parts Increase ↓ Gage Cost Increase | ZM | 0.05 IT11 | IT11 | Low-precision gages recommended to be used to inspect workpieces held to internal (hole) tolerances C11 and H11 and to external (shaft) tolerances c11 and h11. |
| | YM | 0.05 IT9 | IT9 | Gages recommended to be used to inspect workpieces held to internal (hole) tolerances D9 and H9 and to external (shaft) tolerances d9 and h9. |
| | XM | 0.05 IT8 | IT8 | Precision gages recommended to be used to inspect workpieces held to internal (hole) tolerances F8 and H8. |
| | XXM | 0.05 IT7 | IT7 | Recommended to be used for gages to inspect workpieces held to internal (hole) tolerances G7, H7, K7, N7, P7, S7, and U7, and to external (shaft) tolerances f7 and h7. |
| | XXXM | 0.05 IT6 | IT6 | High-precision gages recommended to be used to inspect workpieces held to external (shaft) tolerances g6, h6, k6, n6, p6, s6, and u6. |

^aGagemakers tolerance is equal to 5 per cent of workpiece tolerance or 5 per cent of applicable IT grade value. See table *American National Standard Gagemakers Tolerances ANSI B4.4M-1981, R1994*.

For workpiece tolerance class values, see previous Tables 14, 15, 16, and 17.

**Table 19. American National Standard Gagemakers Tolerances
ANSI B4.4M-1981, R1994**

| Basic Size | | Class ZM (0.05 IT11) | Class YM (0.05 IT9) | Class XM (0.05 IT8) | Class XXM (0.05 IT7) | Class XXXM (0.05 IT6) |
|------------|-----|-------------------------|------------------------|------------------------|-------------------------|--------------------------|
| Over | To | | | | | |
| 0 | 3 | 0.0030 | 0.0012 | 0.0007 | 0.0005 | 0.0003 |
| 3 | 6 | 0.0037 | 0.0015 | 0.0009 | 0.0006 | 0.0004 |
| 6 | 10 | 0.0045 | 0.0018 | 0.0011 | 0.0007 | 0.0005 |
| 10 | 18 | 0.0055 | 0.0021 | 0.0013 | 0.0009 | 0.0006 |
| 18 | 30 | 0.0065 | 0.0026 | 0.0016 | 0.0010 | 0.0007 |
| 30 | 50 | 0.0080 | 0.0031 | 0.0019 | 0.0012 | 0.0008 |
| 50 | 80 | 0.0095 | 0.0037 | 0.0023 | 0.0015 | 0.0010 |
| 80 | 120 | 0.0110 | 0.0043 | 0.0027 | 0.0017 | 0.0011 |
| 120 | 180 | 0.0125 | 0.0050 | 0.0031 | 0.0020 | 0.0013 |
| 180 | 250 | 0.0145 | 0.0057 | 0.0036 | 0.0023 | 0.0015 |
| 250 | 315 | 0.0160 | 0.0065 | 0.0040 | 0.0026 | 0.0016 |
| 315 | 400 | 0.0180 | 0.0070 | 0.0044 | 0.0028 | 0.0018 |
| 400 | 500 | 0.0200 | 0.0077 | 0.0048 | 0.0031 | 0.0020 |

All dimensions are in millimeters. For closer gagemakers tolerance classes than Class XXXM, specify 5 per cent of IT5, IT4, or IT3 and use the designation 0.05 IT5, 0.05 IT4, etc.

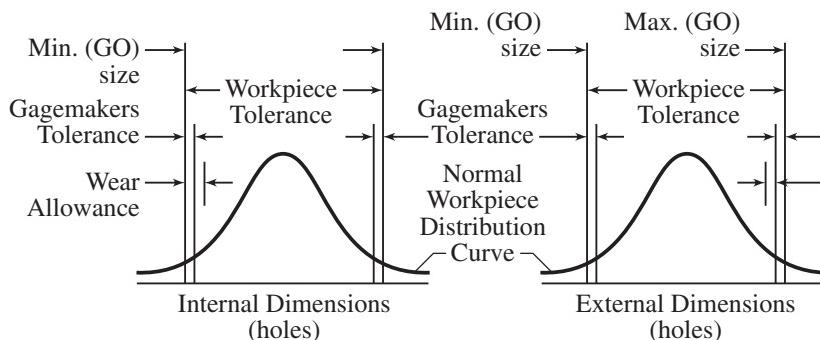


Fig. 4. Relationship between Gagemakers Tolerance, Wear Allowance and Workpiece Tolerance

Relation of Machining Processes to IT Tolerance Grades

Practical Usage of IT Tolerance Grades

CONVERSION FACTORS

In the table of conversion factors that follows, the symbols for SI units, multiples and submultiples are given in parentheses in the right hand column.

Table 1. Metric Conversion Factors

| Multiply | By | To Obtain |
|-------------------------|-------------------------|---|
| Length | | |
| centimeter | 0.03280840 | foot |
| centimeter | 0.3937008 | inch |
| fathom | 1.8288 ^a | meter (m) |
| foot | 0.3048 ^a | meter (m) |
| foot | 30.48 ^a | centimeter (cm) |
| foot | 304.8 ^a | millimeter (mm) |
| inch | 0.0254 ^a | meter (m) |
| inch | 2.54 ^a | centimeter (cm) |
| inch | 25.4 ^a | millimeter (mm) |
| kilometer | 0.6213712 | mile [U.S. statute] |
| meter | 39.37008 | inch |
| meter | 0.5468066 | fathom |
| meter | 3.280840 | foot |
| meter | 0.1988388 | rod |
| meter | 1.093613 | yard |
| meter | 0.0006213712 | mile [U. S. statute] |
| microinch | 0.0254 ^a | micrometer [micron] (μm) |
| micrometer [micron] | 39.37008 | microinch |
| mile [U. S. statute] | 1609.344 ^a | meter (m) |
| mile [U. S. statute] | 1.609344 ^a | kilometer (km) |
| millimeter | 0.003280840 | foot |
| millimeter | 0.03937008 | inch |
| rod | 5.0292 ^a | meter (m) |
| yard | 0.9144 ^a | meter (m) |
| Area | | |
| acre | 4046.856 | meter ² (m^2) |
| acre | 0.4046856 | hectare |
| centimeter ² | 0.1550003 | inch ² |
| centimeter ² | 0.001076391 | foot ² |
| foot ² | 0.09290304 ^a | meter ² (m^2) |
| foot ² | 929.0304 ^a | centimeter ² (cm^2) |
| foot ² | 92,903.04 ^a | millimeter ² (mm^2) |
| hectare | 2.471054 | acre |
| inch ² | 645.16 ^a | millimeter ² (mm^2) |
| inch ² | 6.4516 ^a | centimeter ² (cm^2) |
| inch ² | 0.00064516 ^a | meter ² (m^2) |
| meter ² | 1550.003 | inch ² |
| meter ² | 10.763910 | foot ² |
| meter ² | 1.195990 | yard ² |
| meter ² | 0.0002471054 | acre |

Table 1. (Continued) Metric Conversion Factors

| Multiply | By | To Obtain |
|----------------------------------|----------------------|---|
| mile ² | 2.5900 | kilometer ² |
| millimeter ² | 0.00001076391 | foot ² |
| millimeter ² | 0.001550003 | inch ² |
| yard ² | 0.8361274 | meter ² (m ²) |
| Volume (including Capacity) | | |
| centimeter ³ | 0.06102376 | inch ³ |
| foot ³ | 28.31685 | Liter |
| foot ³ | 28.31685 | Liter |
| gallon [U.K. liquid] | 0.004546092 | meter ³ (m ³) |
| gallon [U.K. liquid] | 4.546092 | Liter |
| gallon [U. S. liquid] | 0.003785412 | meter ³ (m ³) |
| gallon [U.S. liquid] | 3.785412 | Liter |
| inch ³ | 16,387.06 | millimeter ³ (mm ³) |
| inch ³ | 16.38706 | centimeter ³ (cm ³) |
| inch ³ | 0.00001638706 | meter ³ (m ³) |
| Liter | 0.001 ^a | meter ³ (m ³) |
| Liter | 0.2199692 | gallon [U. K. liquid] |
| Liter | 0.2641720 | gallon [U. S. liquid] |
| Liter | 0.03531466 | foot ³ |
| meter ³ | 219.9692 | gallon [U. K. liquid] |
| meter ³ | 264.1720 | gallon [U. S. liquid] |
| meter ³ | 35.31466 | foot ³ |
| meter ³ | 1.307951 | yard ³ |
| meter ³ | 1000. ^a | Liter |
| meter ³ | 61,023.76 | inch ³ |
| millimeter ³ | 0.00006102376 | inch ³ |
| quart[U.S. Liquid] | 0.946 | Liter |
| quart[U.K. Liquid] | 1.136 | Liter |
| yard ³ | 0.7645549 | meter ³ (m ³) |
| Velocity, Acceleration, and Flow | | |
| centimeter/second | 1.968504 | foot/minute |
| centimeter/second | 0.03280840 | foot/second |
| centimeter/minute | 0.3937008 | inch/minute |
| foot/hour | 0.00008466667 | meter/second (m/s) |
| foot/hour | 0.00508 ^a | meter/minute |
| foot/hour | 0.3048 ^a | meter/hour |
| foot/minute | 0.508 ^a | centimeter/second |
| foot/minute | 18.288 ^a | meter/hour |
| foot/minute | 0.3048 ^a | meter/minute |
| foot/minute | 0.00508 ^a | meter/second (m/s) |
| foot/second | 30.48 ^a | centimeter/second |
| foot/second | 18.288 ^a | meter/minute |
| foot/second | 0.3048 ^a | meter/second (m/s) |
| foot/second ² | 0.3048 ^a | meter/second ² (m/s ²) |
| foot ³ /minute | 28.31685 | Liter/minute |

Table 1. (*Continued*) Metric Conversion Factors

| Multiply | By | To Obtain |
|--|-----------------------|--|
| foot ³ /minute | 0.0004719474 | meter ³ /second (m ³ /s) |
| gallon [U. S. liquid]/min. | 0.003785412 | meter ³ /minute |
| gallon [U. S. liquid]/min. | 0.00006309020 | meter ³ /second (m ³ /s) |
| gallon [U. S. liquid]/min. | 0.06309020 | Liter/second |
| gallon [U. S. liquid]/min. | 3.785412 | Liter/minute |
| gallon [U. K. liquid]/min. | 0.004546092 | meter ³ /minute |
| gallon [U. K. liquid]/min. | 0.00007576820 | meter ³ /second (m ³ /s) |
| inch/minute | 25.4 ^a | millimeter/minute |
| inch/minute | 2.54 ^a | centimeter/minute |
| inch/minute | 0.0254 ^a | meter/minute |
| inch/second ² | 0.0254 ^a | meter/second ² (m/s ²) |
| kilometer/hour | 0.6213712 | mile/hour [U. S. statute] |
| Liter/minute | 0.03531466 | foot ³ /minute |
| Liter/minute | 0.2641720 | gallon [U.S. liquid]/minute |
| Liter/second | 15.85032 | gallon [U. S. liquid]/minute |
| mile/hour | 1.609344 ^a | kilometer/hour |
| millimeter/minute | 0.03937008 | inch/minute |
| meter/second | 11,811.02 | foot/hour |
| meter/second | 196.8504 | foot/minute |
| meter/second | 3.280840 | foot/second |
| meter/second ² | 3.280840 | foot/second ² |
| meter/second ² | 39.37008 | inch/second ² |
| meter/minute | 3.280840 | foot/minute |
| meter/minute | 0.05468067 | foot/second |
| meter/minute | 39.37008 | inch/minute |
| meter/hour | 3.280840 | foot/hour |
| meter/hour | 0.05468067 | foot/minute |
| meter ³ /second | 2118.880 | foot ³ /minute |
| meter ³ /second | 13,198.15 | gallon [U. K. liquid]/minute |
| meter ³ /second | 15,850.32 | gallon [U. S. liquid]/minute |
| meter ³ /minute | 219.9692 | gallon [U. K. liquid]/minute |
| meter ³ /minute | 264.1720 | gallon [U. S. liquid]/minute |
| Mass and Density | | |
| grain [$\frac{1}{7000}$ lb avoirdupois] | 0.06479891 | gram (g) |
| gram | 15.43236 | grain |
| gram | 0.001 ^a | kilogram (kg) |
| gram | 0.03527397 | ounce [avoirdupois] |
| gram | 0.03215074 | ounce [troy] |
| gram/centimeter ³ | 0.03612730 | pound/inch ³ |
| hundredweight [long] | 50.80235 | kilogram (kg) |
| hundredweight [short] | 45.35924 | kilogram (kg) |
| kilogram | 1000. ^a | gram (g) |
| kilogram | 35.27397 | ounce [avoirdupois] |
| kilogram | 32.15074 | ounce [troy] |

Table 1. (*Continued*) Metric Conversion Factors

| Multiply | By | To Obtain |
|-----------------------------|-----------------------|---|
| kilogram | 2.04622 | pound [avoirdupois] |
| kilogram | 0.06852178 | slug |
| kilogram | 0.0009842064 | ton [long] |
| kilogram | 0.001102311 | ton [short] |
| kilogram | 0.001 ^a | ton [metric] |
| kilogram | 0.001 ^a | tonne |
| kilogram | 0.01968413 | hundredweight [long] |
| kilogram | 0.02204622 | hundredweight [short] |
| kilogram/meter ³ | 0.06242797 | pound/foot ³ |
| kilogram/meter ³ | 0.01002242 | pound/gallon [U. K. liquid] |
| kilogram/meter ³ | 0.008345406 | pound/gallon [U. S. liquid] |
| ounce [avoirdupois] | 28.34952 | gram (g) |
| ounce [avoirdupois] | 0.02834952 | kilogram (kg) |
| ounce [troy] | 31.10348 | gram (g) |
| ounce [troy] | 0.03110348 | kilogram (kg) |
| pound [avoirdupois] | 0.4535924 | kilogram (kg) |
| pound/foot ³ | 16.01846 | kilogram/meter ³ (kg/m ³) |
| pound/inch ³ | 27.67990 | gram/centimeter ³ (g/cm ³) |
| pound/gal [U. S. liquid] | 119.8264 | kilogram/meter ³ (kg/m ³) |
| pound/gal [U. K. liquid] | 99.77633 | kilogram/meter ³ (kg/m ³) |
| slug | 14.59390 | kilogram (kg) |
| ton [long 2240 lb] | 1016.047 | kilogram (kg) |
| ton [short 2000 lb] | 907.1847 | kilogram (kg) |
| ton [metric] | 1000. ^a | kilogram (kg) |
| ton [Metric] | 0.9842 | ton[long 2240 lb] |
| ton [Metric] | 1.1023 | ton[short 2000 lb] |
| tonne | 1000. ^a | kilogram (kg) |
| Force and Force/Length | | |
| dyne | 0.00001 ^a | newton (N) |
| kilogram-force | 9.806650 ^a | newton (N) |
| kilopound | 9.806650 ^a | newton (N) |
| newton | 0.1019716 | kilogram-force |
| newton | 0.1019716 | kilopound |
| newton | 0.2248089 | pound-force |
| newton | 100,000. ^a | dyne |
| newton | 7.23301 | poundal |
| newton | 3.596942 | ounce-force |
| newton/meter | 0.005710148 | pound/inch |
| newton/meter | 0.06852178 | pound/foot |
| ounce-force | 0.2780139 | newton (N) |
| pound-force | 4.448222 | newton (N) |
| poundal | 0.1382550 | newton (N) |
| pound/inch | 175.1268 | newton/meter (N/m) |
| pound/foot | 14.59390 | newton/meter (N/m) |

Table 1. (*Continued*) Metric Conversion Factors

| Multiply | By | To Obtain |
|--|--------------------------|--|
| Bending Moment or Torque | | |
| dyne-centimeter | 0.0000001 ^a | newton-meter (N · m) |
| kilogram-meter | 9.806650 ^a | newton-meter (N · m) |
| ounce-inch | 7.061552 | newton-millimeter |
| ounce-inch | 0.007061552 | newton-meter (N · m) |
| newton-meter | 0.7375621 | pound-foot |
| newton-meter | 10,000,000. ^a | dyne-centimeter |
| newton-meter | 0.1019716 | kilogram-meter |
| newton-meter | 141.6119 | ounce-inch |
| newton-millimeter | 0.1416119 | ounce-inch |
| pound-foot | 1.355818 | newton-meter (N · m) |
| Moment Of Inertia and Section Modulus | | |
| moment of inertia [kg · m ²] | 23.73036 | pound-foot ² |
| moment of inertia [kg · m ²] | 3417.171 | pound-inch ² |
| moment of inertia [lb · ft ²] | 0.04214011 | kilogram-meter ² (kg · m ²) |
| moment of inertia [lb · inch ²] | 0.0002926397 | kilogram-meter ² (kg · m ²) |
| moment of section [foot ⁴] | 0.008630975 | meter ⁴ (m ⁴) |
| moment of section [inch ⁴] | 41.62314 | centimeter ⁴ |
| moment of section [meter ⁴] | 115.8618 | foot ⁴ |
| moment of section [centimeter ⁴] | 0.02402510 | inch ⁴ |
| section modulus [foot ³] | 0.02831685 | meter ³ (m ³) |
| section modulus [inch ³] | 0.00001638706 | meter ³ (m ³) |
| section modulus [meter ³] | 35.31466 | foot ³ |
| section modulus [meter ³] | 61,023.76 | inch ³ |
| Momentum | | |
| kilogram-meter/second | 7.233011 | pound-foot/second |
| kilogram-meter/second | 86.79614 | pound-inch/second |
| pound-foot/second | 0.1382550 | kilogram-meter/second (kg · m/s) |
| pound-inch/second | 0.01152125 | kilogram-meter/second (kg · m/s) |
| Pressure and Stress | | |
| atmosphere [14.6959 lb/inch ²] | 101,325. | pascal (Pa) |
| bar | 100,000. ^a | pascal (Pa) |
| bar | 14.50377 | pound/inch ² |
| bar | 100,000. ^a | newton/meter ² (N/m ²) |
| hectobar | 0.6474898 | ton [long]/inch ² |
| kilogram/centimeter ² | 14.22334 | pound/inch ² |
| kilogram/meter ² | 9.806650 ^a | newton/meter ² (N/m ²) |
| kilogram/meter ² | 9.806650 ^a | pascal (Pa) |
| kilogram/meter ² | 0.2048161 | pound/foot ² |
| kilonewton/meter ² | 0.1450377 | pound/inch ² |
| newton/centimeter ² | 1.450377 | pound/inch ² |
| newton/meter ² | 0.00001 ^a | bar |
| newton/meter ² | 1.0 ^a | pascal (Pa) |

Table 1. (*Continued*) Metric Conversion Factors

| Multiply | By | To Obtain |
|--------------------------------|----------------------|---|
| newton/meter ² | 0.0001450377 | pound/inch ² |
| newton/meter ² | 0.1019716 | kilogram/meter ² |
| newton/millimeter ² | 145.0377 | pound/inch ² |
| pascal | 0.00000986923 | atmosphere |
| pascal | 0.00001 ^a | bar |
| pascal | 0.1019716 | kilogram/meter ² |
| pascal | 1.0 ^a | newton/meter ² (N/m ²) |
| pascal | 0.02088543 | pound/foot ² |
| pascal | 0.0001450377 | pound/inch ² |
| pound/foot ² | 4.882429 | kilogram/meter ² |
| pound/foot ² | 47.88026 | pascal (Pa) |
| pound/inch ² | 0.06894757 | bar |
| pound/inch ² | 0.07030697 | kilogram/centimeter ² |
| pound/inch ² | 0.6894757 | newton/centimeter ² |
| pound/inch ² | 6.894757 | kilonewton/meter ² |
| pound/inch ² | 6894.757 | newton/meter ² (N/m ²) |
| pound/inch ² | 0.006894757 | newton/millimeter ² (N/mm ²) |
| pound/inch ² | 6894.757 | pascal (Pa) |
| ton [long]/inch ² | 1.544426 | hectobar |
| Energy and Work | | |
| Btu [International Table] | 1055.056 | joule (J) |
| Btu [mean] | 1055.87 | joule (J) |
| calorie [mean] | 4.19002 | joule (J) |
| foot-pound | 1.355818 | joule (J) |
| foot-poundal | 0.04214011 | joule (J) |
| joule | 0.0009478170 | Btu [International Table] |
| joule | 0.0009470863 | Btu [mean] |
| joule | 0.2386623 | calorie [mean] |
| joule | 0.7375621 | foot-pound |
| joule | 23.73036 | foot-poundal |
| joule | 0.9998180 | joule [International U. S.] |
| joule | 0.9999830 | joule [U. S. legal, 1948] |
| joule [International U. S.] | 1.000182 | joule (J) |
| joule [U. S. legal, 1948] | 1.000017 | joule (J) |
| joule | .0002777778 | watt-hour |
| watt-hour | 3600. ^a | joule (J) |
| Power | | |
| Btu [International Table]/hour | 0.2930711 | watt (W) |
| foot-pound/hour | 0.0003766161 | watt (W) |
| foot-pound/minute | 0.02259697 | watt (W) |
| horsepower [550 ft-lb/s] | 0.7456999 | kilowatt (kW) |
| horsepower [550 ft-lb/s] | 745.6999 | watt (W) |
| horsepower [electric] | 746. ^a | watt (W) |
| horsepower [metric] | 735.499 | watt (W) |
| horsepower [U. K.] | 745.70 | watt (W) |
| kilowatt | 1.341022 | horsepower [550 ft-lb/s] |

Table 1. (*Continued*) Metric Conversion Factors

| Multiply | By | To Obtain |
|-------------------------------|-------------------------------|--|
| watt | 2655.224 | foot-pound/hour |
| watt | 44.25372 | foot-pound/minute |
| watt | 0.001341022 | horsepower [550 ft-lb/s] |
| watt | 0.001340483 | horsepower [electric] |
| watt | 0.001359621 | horsepower [metric] |
| watt | 0.001341022 | horsepower [U. K.] |
| watt | 3.412141 | Btu [International Table]/hour |
| Viscosity | | |
| centipoise | 0.001 ^a | pascal-second (Pa · s) |
| centistoke | 0.000001 ^a | meter ² /second (m ² /s) |
| meter ² /second | 1,000,000. ^a | centistoke |
| meter ² /second | 10,000. ^a | stoke |
| pascal-second | 1000. ^a | centipoise |
| pascal-second | 10. ^a | poise |
| poise | 0.1 ^a | pascal-second (Pa · s) |
| stoke | 0.0001 ^a | meter ² /second (m ² /s) |
| Temperature | | |
| To Convert From | To | Use Formula |
| temperature Celsius, t_C | temperature Kelvin, t_K | $t_K = t_C + 273.15$ |
| temperature Fahrenheit, t_F | temperature Kelvin, t_K | $t_K = (t_F + 459.67)/1.8$ |
| temperature Celsius, t_C | temperature Fahrenheit, t_F | $t_F = 1.8 t_C + 32$ |
| temperature Fahrenheit, t_F | temperature Celsius, t_C | $t_C = (t_F - 32)/1.8$ |
| temperature Kelvin, t_K | temperature Celsius, t_C | $t_C = t_K - 273.15$ |
| temperature Kelvin, t_K | temperature Fahrenheit, t_F | $t_F = 1.8 t_K - 459.67$ |
| temperature Kelvin, t_K | temperature Rankine, t_R | $t_R = 9/5 t_K$ |
| temperature Rankine, t_R | temperature Kelvin, t_K | $t_K = 5/9 t_R$ |

^aThe figure is exact.

The right-hand column shows symbols of SI units, multiples and sub-multiples in parentheses.

Table 2. Factors and Prefixes for Forming Decimal Multiples and Sub-multiples of the SI Units

| Number | Power | Prefix | Subdivisions or Multiples | Example based on meter | Symbol |
|-------------------|-----------|--------|---------------------------|------------------------|--------|
| 1E-06 | 10^{-6} | micro | one-millionth | micrometer | μ |
| 0.001 | 10^{-3} | milli | one-thousandth | millimeter | m |
| 0.01 | 10^{-2} | centi | one-hundredth | centimeter | c |
| 0.1 | 10^{-1} | deci | one-tenth | decimeter | d |
| 1 | 10^0 | ... | one | meter | ... |
| 10 | 10^1 | deka | ten | dekameter | da |
| 100 | 10^2 | hecto | one hundred | hectometer | h |
| 1,000 | 10^3 | kilo | one thousand | kilometer | k |
| 1,000,000 | 10^6 | mega | one million | megameter | M |
| 1,000,000,000 | 10^9 | giga | one billion | gigameter | G |
| 1,000,000,000,000 | 10^{12} | tera | one trillion | terameter | T |

Use of Conversion Tables.—On this and following pages, tables are given that permit conversion between English and metric units over a wide range of values. Where the desired value cannot be obtained directly from these tables, a simple addition of two or more values taken directly from the table will suffice as shown in the following examples:

Example 1: Find the millimeter equivalent of 0.4476 inch.

$$\begin{array}{rcl} 4 & \text{in} & = 10.1600 \text{ mm} \\ .04 & \text{in} & = 1.01600 \text{ mm} \\ .007 & \text{in} & = 0.17780 \text{ mm} \\ \hline .0006 & \text{in} & = 0.01524 \text{ mm} \\ \hline .4476 & \text{in} & = 11.36904 \text{ mm} \end{array}$$

Example 2: Find the inch equivalent of 84.9 mm.

$$\begin{array}{rcl} 80. & \text{mm} & = 3.14961 \text{ in} \\ 4. & \text{mm} & = 0.15748 \text{ in} \\ \hline 0.9 & \text{mm} & = 0.03543 \text{ in} \\ \hline 84.9 & \text{mm} & = 3.34252 \text{ in} \end{array}$$

Table 3. Inch — Millimeter and Inch — Centimeter Conversion Table
(Based on 1 inch = 25.4 millimeters, exactly)

| Inches To Millimeters | | | | | | | | | |
|-----------------------|-------------|-----|-----------|-----|----------|-----|---------|-------|---------|
| in. | mm | in. | mm | in. | mm | in. | mm | in. | mm |
| 10 | 254.00000 | 1 | 25.40000 | 0.1 | 2.54000 | .01 | 0.25400 | 0.001 | 0.02540 |
| 20 | 508.00000 | 2 | 50.80000 | 0.2 | 5.08000 | .02 | 0.50800 | 0.002 | 0.05080 |
| 30 | 762.00000 | 3 | 76.20000 | 0.3 | 7.62000 | .03 | 0.76200 | 0.003 | 0.07620 |
| 40 | 1,016.00000 | 4 | 101.60000 | 0.4 | 10.16000 | .04 | 1.01600 | 0.004 | 0.10160 |
| 50 | 1,270.00000 | 5 | 127.00000 | 0.5 | 12.70000 | .05 | 1.27000 | 0.005 | 0.12700 |
| 60 | 1,524.00000 | 6 | 152.40000 | 0.6 | 15.24000 | .06 | 1.52400 | 0.006 | 0.15240 |
| 70 | 1,778.00000 | 7 | 177.80000 | 0.7 | 17.78000 | .07 | 1.77800 | 0.007 | 0.17780 |
| 80 | 2,032.00000 | 8 | 203.20000 | 0.8 | 20.32000 | .08 | 2.03200 | 0.008 | 0.20320 |
| 90 | 2,286.00000 | 9 | 228.60000 | 0.9 | 22.86000 | .09 | 2.28600 | 0.009 | 0.22860 |
| 100 | 2,540.00000 | 10 | 254.00000 | 1.0 | 25.40000 | .10 | 2.54000 | 0.010 | 0.25400 |
| Millimeters To Inches | | | | | | | | | |
| mm | in. | mm | in. | mm | in. | mm | in. | mm | in. |
| 100 | 3.93701 | 10 | 0.39370 | 1 | 0.03937 | 0.1 | 0.00394 | 0.01 | 0.00039 |
| 200 | 7.87402 | 20 | 0.78740 | 2 | 0.07874 | 0.2 | 0.00787 | 0.02 | 0.00079 |
| 300 | 11.81102 | 30 | 1.18110 | 3 | 0.11811 | 0.3 | 0.01181 | 0.03 | 0.00118 |
| 400 | 15.74803 | 40 | 1.57480 | 4 | 0.15748 | 0.4 | 0.01575 | 0.04 | 0.00157 |
| 500 | 19.68504 | 50 | 1.96850 | 5 | 0.19685 | 0.5 | 0.01969 | 0.05 | 0.00197 |
| 600 | 23.62205 | 60 | 2.36220 | 6 | 0.23622 | 0.6 | 0.02362 | 0.06 | 0.00236 |
| 700 | 27.55906 | 70 | 2.75591 | 7 | 0.27559 | 0.7 | 0.02756 | 0.07 | 0.00276 |
| 800 | 31.49606 | 80 | 3.14961 | 8 | 0.31496 | 0.8 | 0.03150 | 0.08 | 0.00315 |
| 900 | 35.43307 | 90 | 3.54331 | 9 | 0.35433 | 0.9 | 0.03543 | 0.09 | 0.00354 |
| 1,000 | 39.37008 | 100 | 3.93701 | 10 | 0.39370 | 1.0 | 0.03937 | 0.10 | 0.00394 |

For inches to centimeters, shift decimal point in mm column one place to left and read centimeters, thus:

$$40 \text{ in.} = 1016 \text{ mm} = 101.6 \text{ cm}$$

For centimeters to inches, shift decimal point of centimeter value one place to right and enter mm column, thus:

$$70 \text{ cm} = 700 \text{ mm} = 27.55906 \text{ inches}$$

Table 4. Decimals of an Inch to Millimeters
 (Based on 1 inch = 25.4 millimeters, exactly)

| Inches | 0.000 | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 | 0.009 |
|-------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Millimeters | | | | | | | | | | |
| 0.000 | ... | 0.0254 | 0.0508 | 0.0762 | 0.1016 | 0.1270 | 0.1524 | 0.1778 | 0.2032 | 0.2286 |
| 0.010 | 0.2540 | 0.2794 | 0.3048 | 0.3302 | 0.3556 | 0.3810 | 0.4064 | 0.4318 | 0.4572 | 0.4826 |
| 0.020 | 0.5080 | 0.5334 | 0.5588 | 0.5842 | 0.6096 | 0.6350 | 0.6604 | 0.6858 | 0.7112 | 0.7366 |
| 0.030 | 0.7620 | 0.7874 | 0.8128 | 0.8382 | 0.8636 | 0.8890 | 0.9144 | 0.9398 | 0.9652 | 0.9906 |
| 0.040 | 1.0160 | 1.0414 | 1.0668 | 1.0922 | 1.1176 | 1.1430 | 1.1684 | 1.1938 | 1.2192 | 1.2446 |
| 0.050 | 1.2700 | 1.2954 | 1.3208 | 1.3462 | 1.3716 | 1.3970 | 1.4224 | 1.4478 | 1.4732 | 1.4986 |
| 0.060 | 1.5240 | 1.5494 | 1.5748 | 1.6002 | 1.6256 | 1.6510 | 1.6764 | 1.7018 | 1.7272 | 1.7526 |
| 0.070 | 1.7780 | 1.8034 | 1.8288 | 1.8542 | 1.8796 | 1.9050 | 1.9304 | 1.9558 | 1.9812 | 2.0066 |
| 0.080 | 2.0320 | 2.0574 | 2.0828 | 2.1082 | 2.1336 | 2.1590 | 2.1844 | 2.2098 | 2.2352 | 2.2606 |
| 0.090 | 2.2860 | 2.3114 | 2.3368 | 2.3622 | 2.3876 | 2.4130 | 2.4384 | 2.4638 | 2.4892 | 2.5146 |
| 0.100 | 2.5400 | 2.5654 | 2.5908 | 2.6162 | 2.6416 | 2.6670 | 2.6924 | 2.7178 | 2.7432 | 2.7686 |
| 0.110 | 2.7940 | 2.8194 | 2.8448 | 2.8702 | 2.8956 | 2.9210 | 2.9464 | 2.9718 | 2.9972 | 3.0226 |
| 0.120 | 3.0480 | 3.0734 | 3.0988 | 3.1242 | 3.1496 | 3.1750 | 3.2004 | 3.2258 | 3.2512 | 3.2766 |
| 0.130 | 3.3020 | 3.3274 | 3.3528 | 3.3782 | 3.4036 | 3.4290 | 3.4544 | 3.4798 | 3.5052 | 3.5306 |
| 0.140 | 3.5560 | 3.5814 | 3.6068 | 3.6322 | 3.6576 | 3.6830 | 3.7084 | 3.7338 | 3.7592 | 3.7846 |
| 0.150 | 3.8100 | 3.8354 | 3.8608 | 3.8862 | 3.9116 | 3.9370 | 3.9624 | 3.9878 | 4.0132 | 4.0386 |
| 0.160 | 4.0640 | 4.0894 | 4.1148 | 4.1402 | 4.1656 | 4.1910 | 4.2164 | 4.2418 | 4.2672 | 4.2926 |
| 0.170 | 4.3180 | 4.3434 | 4.3688 | 4.3942 | 4.4196 | 4.4450 | 4.4704 | 4.4958 | 4.5212 | 4.5466 |
| 0.180 | 4.5720 | 4.5974 | 4.6228 | 4.6482 | 4.6736 | 4.6990 | 4.7244 | 4.7498 | 4.7752 | 4.8006 |
| 0.190 | 4.8260 | 4.8514 | 4.8768 | 4.9022 | 4.9276 | 4.9530 | 4.9784 | 5.0038 | 5.0292 | 5.0546 |
| 0.200 | 5.0800 | 5.1054 | 5.1308 | 5.1562 | 5.1816 | 5.2070 | 5.2324 | 5.2578 | 5.2832 | 5.3086 |
| 0.210 | 5.3340 | 5.3594 | 5.3848 | 5.4102 | 5.4356 | 5.4610 | 5.4864 | 5.5118 | 5.5372 | 5.5626 |
| 0.220 | 5.5880 | 5.6134 | 5.6388 | 5.6642 | 5.6896 | 5.7150 | 5.7404 | 5.7658 | 5.7912 | 5.8166 |
| 0.230 | 5.8420 | 5.8674 | 5.8928 | 5.9182 | 5.9436 | 5.9690 | 5.9944 | 6.0198 | 6.0452 | 6.0706 |
| 0.240 | 6.0960 | 6.1214 | 6.1468 | 6.1722 | 6.1976 | 6.2230 | 6.2484 | 6.2738 | 6.2992 | 6.3246 |
| 0.250 | 6.3500 | 6.3754 | 6.4008 | 6.4262 | 6.4516 | 6.4770 | 6.5024 | 6.5278 | 6.5532 | 6.5786 |
| 0.260 | 6.6040 | 6.6294 | 6.6548 | 6.6802 | 6.7056 | 6.7310 | 6.7564 | 6.7818 | 6.8072 | 6.8326 |
| 0.270 | 6.8580 | 6.8834 | 6.9088 | 6.9342 | 6.9596 | 6.9850 | 7.0104 | 7.0358 | 7.0612 | 7.0866 |
| 0.280 | 7.1120 | 7.1374 | 7.1628 | 7.1882 | 7.2136 | 7.2390 | 7.2644 | 7.2898 | 7.3152 | 7.3406 |
| 0.290 | 7.3660 | 7.3914 | 7.4168 | 7.4422 | 7.4676 | 7.4930 | 7.5184 | 7.5438 | 7.5692 | 7.5946 |
| 0.300 | 7.6200 | 7.6454 | 7.6708 | 7.6962 | 7.7216 | 7.7470 | 7.7724 | 7.7978 | 7.8232 | 7.8486 |
| 0.310 | 7.8740 | 7.8994 | 7.9248 | 7.9502 | 7.9756 | 8.0010 | 8.0264 | 8.0518 | 8.0772 | 8.1026 |
| 0.320 | 8.1280 | 8.1534 | 8.1788 | 8.2042 | 8.2296 | 8.2550 | 8.2804 | 8.3058 | 8.3312 | 8.3566 |
| 0.330 | 8.3820 | 8.4074 | 8.4328 | 8.4582 | 8.4836 | 8.5090 | 8.5344 | 8.5598 | 8.5852 | 8.6106 |
| 0.340 | 8.6360 | 8.6614 | 8.6868 | 8.7122 | 8.7376 | 8.7630 | 8.7884 | 8.8138 | 8.8392 | 8.8646 |
| 0.350 | 8.8900 | 8.9154 | 8.9408 | 8.9662 | 8.9916 | 9.0170 | 9.0424 | 9.0678 | 9.0932 | 9.1186 |
| 0.360 | 9.1440 | 9.1694 | 9.1948 | 9.2202 | 9.2456 | 9.2710 | 9.2964 | 9.3218 | 9.3472 | 9.3726 |
| 0.370 | 9.3980 | 9.4234 | 9.4488 | 9.4742 | 9.4996 | 9.5250 | 9.5504 | 9.5758 | 9.6012 | 9.6266 |
| 0.380 | 9.6520 | 9.6774 | 9.7028 | 9.7282 | 9.7536 | 9.7790 | 9.8044 | 9.8298 | 9.8552 | 9.8806 |
| 0.390 | 9.9060 | 9.9314 | 9.9568 | 9.9822 | 10.0076 | 10.0330 | 10.0584 | 10.0838 | 10.1092 | 10.1346 |
| 0.400 | 10.1600 | 10.1854 | 10.2108 | 10.2362 | 10.2616 | 10.2870 | 10.3124 | 10.3378 | 10.3632 | 10.3886 |
| 0.410 | 10.4140 | 10.4394 | 10.4648 | 10.4902 | 10.5156 | 10.5410 | 10.5664 | 10.5918 | 10.6172 | 10.6426 |
| 0.420 | 10.6680 | 10.6934 | 10.7188 | 10.7442 | 10.7696 | 10.7950 | 10.8204 | 10.8458 | 10.8712 | 10.8966 |
| 0.430 | 10.9220 | 10.9474 | 10.9728 | 10.9982 | 11.0236 | 11.0490 | 11.0744 | 11.0998 | 11.1252 | 11.1506 |
| 0.440 | 11.1760 | 11.2014 | 11.2268 | 11.2522 | 11.2776 | 11.3030 | 11.3284 | 11.3538 | 11.3792 | 11.4046 |
| 0.450 | 11.4300 | 11.4554 | 11.4808 | 11.5062 | 11.5316 | 11.5570 | 11.5824 | 11.6078 | 11.6332 | 11.6586 |
| 0.460 | 11.6840 | 11.7094 | 11.7348 | 11.7602 | 11.7856 | 11.8110 | 11.8364 | 11.8618 | 11.8872 | 11.9126 |
| 0.470 | 11.9380 | 11.9634 | 11.9888 | 12.0142 | 12.0396 | 12.0650 | 12.0904 | 12.1158 | 12.1412 | 12.1666 |
| 0.480 | 12.1920 | 12.2174 | 12.2428 | 12.2682 | 12.2936 | 12.3190 | 12.3444 | 12.3698 | 12.3952 | 12.4206 |
| 0.490 | 12.4460 | 12.4714 | 12.4968 | 12.5222 | 12.5476 | 12.5730 | 12.5984 | 12.6238 | 12.6492 | 12.6746 |
| 0.500 | 12.7000 | 12.7254 | 12.7508 | 12.7762 | 12.8016 | 12.8270 | 12.8524 | 12.8778 | 12.9032 | 12.9286 |
| 0.510 | 12.9540 | 12.9794 | 13.0048 | 13.0302 | 13.0556 | 13.0810 | 13.1064 | 13.1318 | 13.1572 | 13.1826 |

Table 4. (Continued) Decimals of an Inch to Millimeters
 (Based on 1inch = 25.4 millimeters, exactly)

| Inches | 0.000 | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 | 0.009 |
|-------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Millimeters | | | | | | | | | | |
| 0.520 | 13.2080 | 13.2334 | 13.2588 | 13.2842 | 13.3096 | 13.3350 | 13.3604 | 13.3858 | 13.4112 | 13.4366 |
| 0.530 | 13.4620 | 13.4874 | 13.5128 | 13.5382 | 13.5636 | 13.5890 | 13.6144 | 13.6398 | 13.6652 | 13.6906 |
| 0.540 | 13.7160 | 13.7414 | 13.7668 | 13.7922 | 13.8176 | 13.8430 | 13.8684 | 13.8938 | 13.9192 | 13.9446 |
| 0.550 | 13.9700 | 13.9954 | 14.0208 | 14.0462 | 14.0716 | 14.0970 | 14.1224 | 14.1478 | 14.1732 | 14.1986 |
| 0.560 | 14.2240 | 14.2494 | 14.2748 | 14.3002 | 14.3256 | 14.3510 | 14.3764 | 14.4018 | 14.4272 | 14.4526 |
| 0.570 | 14.4780 | 14.5034 | 14.5288 | 14.5542 | 14.5796 | 14.6050 | 14.6304 | 14.6558 | 14.6812 | 14.7066 |
| 0.580 | 14.7320 | 14.7574 | 14.7828 | 14.8082 | 14.8336 | 14.8590 | 14.8844 | 14.9098 | 14.9352 | 14.9606 |
| 0.590 | 14.9860 | 15.0114 | 15.0368 | 15.0622 | 15.0876 | 15.1130 | 15.1384 | 15.1638 | 15.1892 | 15.2146 |
| 0.600 | 15.2400 | 15.2654 | 15.2908 | 15.3162 | 15.3416 | 15.3670 | 15.3924 | 15.4178 | 15.4432 | 15.4686 |
| 0.610 | 15.4940 | 15.5194 | 15.5448 | 15.5702 | 15.5956 | 15.6210 | 15.6464 | 15.6718 | 15.6972 | 15.7226 |
| 0.620 | 15.7480 | 15.7734 | 15.7988 | 15.8242 | 15.8496 | 15.8750 | 15.9004 | 15.9258 | 15.9512 | 15.9766 |
| 0.630 | 16.0020 | 16.0274 | 16.0528 | 16.0782 | 16.1036 | 16.1290 | 16.1544 | 16.1798 | 16.2052 | 16.2306 |
| 0.640 | 16.2560 | 16.2814 | 16.3068 | 16.3322 | 16.3576 | 16.3830 | 16.4084 | 16.4338 | 16.4592 | 16.4846 |
| 0.650 | 16.5100 | 16.5354 | 16.5608 | 16.5862 | 16.6116 | 16.6370 | 16.6624 | 16.6878 | 16.7132 | 16.7386 |
| 0.660 | 16.7640 | 16.7894 | 16.8148 | 16.8402 | 16.8656 | 16.8910 | 16.9164 | 16.9418 | 16.9672 | 16.9926 |
| 0.670 | 17.0180 | 17.0434 | 17.0688 | 17.0942 | 17.1196 | 17.1450 | 17.1704 | 17.1958 | 17.2212 | 17.2466 |
| 0.680 | 17.2720 | 17.2974 | 17.3228 | 17.3482 | 17.3736 | 17.3990 | 17.4244 | 17.4498 | 17.4752 | 17.5006 |
| 0.690 | 17.5260 | 17.5514 | 17.5768 | 17.6022 | 17.6276 | 17.6530 | 17.6784 | 17.7038 | 17.7292 | 17.7546 |
| 0.700 | 17.7800 | 17.8054 | 17.8308 | 17.8562 | 17.8816 | 17.9070 | 17.9324 | 17.9578 | 17.9832 | 18.0086 |
| 0.710 | 18.0340 | 18.0594 | 18.0848 | 18.1102 | 18.1356 | 18.1610 | 18.1864 | 18.2118 | 18.2372 | 18.2626 |
| 0.720 | 18.2880 | 18.3134 | 18.3388 | 18.3642 | 18.3896 | 18.4150 | 18.4404 | 18.4658 | 18.4912 | 18.5166 |
| 0.730 | 18.5420 | 18.5674 | 18.5928 | 18.6182 | 18.6436 | 18.6690 | 18.6944 | 18.7198 | 18.7452 | 18.7706 |
| 0.740 | 18.7960 | 18.8214 | 18.8468 | 18.8722 | 18.8976 | 18.9230 | 18.9484 | 18.9738 | 18.9992 | 19.0246 |
| 0.750 | 19.0500 | 19.0754 | 19.1008 | 19.1262 | 19.1516 | 19.1770 | 19.2024 | 19.2278 | 19.2532 | 19.2786 |
| 0.760 | 19.3040 | 19.3294 | 19.3548 | 19.3802 | 19.4056 | 19.4310 | 19.4564 | 19.4818 | 19.5072 | 19.5326 |
| 0.770 | 19.5580 | 19.5834 | 19.6088 | 19.6342 | 19.6596 | 19.6850 | 19.7104 | 19.7358 | 19.7612 | 19.7866 |
| 0.780 | 19.8120 | 19.8374 | 19.8628 | 19.8882 | 19.9136 | 19.9390 | 19.9644 | 19.9898 | 20.0152 | 20.0406 |
| 0.790 | 20.0660 | 20.0914 | 20.1168 | 20.1422 | 20.1676 | 20.1930 | 20.2184 | 20.2438 | 20.2692 | 20.2946 |
| 0.800 | 20.3200 | 20.3454 | 20.3708 | 20.3962 | 20.4216 | 20.4470 | 20.4724 | 20.4978 | 20.5232 | 20.5486 |
| 0.810 | 20.5740 | 20.5994 | 20.6248 | 20.6502 | 20.6756 | 20.7010 | 20.7264 | 20.7518 | 20.7772 | 20.8026 |
| 0.820 | 20.8280 | 20.8534 | 20.8788 | 20.9042 | 20.9296 | 20.9550 | 20.9804 | 21.0058 | 21.0312 | 21.0566 |
| 0.830 | 21.0820 | 21.1074 | 21.1328 | 21.1582 | 21.1836 | 21.2090 | 21.2344 | 21.2598 | 21.2852 | 21.3106 |
| 0.840 | 21.3360 | 21.3614 | 21.3868 | 21.4122 | 21.4376 | 21.4630 | 21.4884 | 21.5138 | 21.5392 | 21.5646 |
| 0.850 | 21.5900 | 21.6154 | 21.6408 | 21.6662 | 21.6916 | 21.7170 | 21.7424 | 21.7678 | 21.7932 | 21.8186 |
| 0.860 | 21.8440 | 21.8694 | 21.8948 | 21.9202 | 21.9456 | 21.9710 | 21.9964 | 22.0218 | 22.0472 | 22.0726 |
| 0.870 | 22.0980 | 22.1234 | 22.1488 | 22.1742 | 22.1996 | 22.2250 | 22.2504 | 22.2758 | 22.3012 | 22.3266 |
| 0.880 | 22.3520 | 22.3774 | 22.4028 | 22.4282 | 22.4536 | 22.4790 | 22.5044 | 22.5298 | 22.5552 | 22.5806 |
| 0.890 | 22.6060 | 22.6314 | 22.6568 | 22.6822 | 22.7076 | 22.7330 | 22.7584 | 22.7838 | 22.8092 | 22.8346 |
| 0.900 | 22.8600 | 22.8854 | 22.9108 | 22.9362 | 22.9616 | 22.9870 | 23.0124 | 23.0378 | 23.0632 | 23.0886 |
| 0.910 | 23.1140 | 23.1394 | 23.1648 | 23.1902 | 23.2156 | 23.2410 | 23.2664 | 23.2918 | 23.3172 | 23.3426 |
| 0.920 | 23.3680 | 23.3934 | 23.4188 | 23.4442 | 23.4696 | 23.4950 | 23.5204 | 23.5458 | 23.5712 | 23.5966 |
| 0.930 | 23.6220 | 23.6474 | 23.6728 | 23.6982 | 23.7236 | 23.7490 | 23.7744 | 23.7998 | 23.8252 | 23.8506 |
| 0.940 | 23.8760 | 23.9014 | 23.9268 | 23.9522 | 23.9776 | 24.0030 | 24.0284 | 24.0538 | 24.0792 | 24.1046 |
| 0.950 | 24.1300 | 24.1554 | 24.1808 | 24.2062 | 24.2316 | 24.2570 | 24.2824 | 24.3078 | 24.3332 | 24.3586 |
| 0.960 | 24.3840 | 24.4094 | 24.4348 | 24.4602 | 24.4856 | 24.5110 | 24.5364 | 24.5618 | 24.5872 | 24.6126 |
| 0.970 | 24.6380 | 24.6634 | 24.6888 | 24.7142 | 24.7396 | 24.7650 | 24.7904 | 24.8158 | 24.8412 | 24.8666 |
| 0.980 | 24.8920 | 24.9174 | 24.9428 | 24.9682 | 24.9936 | 25.0190 | 25.0444 | 25.0698 | 25.0952 | 25.1206 |
| 0.990 | 25.1460 | 25.1714 | 25.1968 | 25.2222 | 25.2476 | 25.2730 | 25.2984 | 25.3238 | 25.3492 | 25.3746 |
| 1.000 | 25.4000 | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Use Table 3 to obtain whole inch equivalents to add to decimal equivalents above. All values given in this table are exact; figures to the right of the last place figures are all zeros.

Table 5. Millimeters to Inches
 (Based on 1 inch = 25.4 millimeters, exactly)

| Millimeters | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Inches | | | | | | | | | | |
| 0 | ... | 0.03937 | 0.07874 | 0.11811 | 0.15748 | 0.19685 | 0.23622 | 0.27559 | 0.31496 | 0.35433 |
| 10 | 0.39370 | 0.43307 | 0.47244 | 0.51181 | 0.55118 | 0.59055 | 0.62992 | 0.66929 | 0.70866 | 0.74803 |
| 20 | 0.78740 | 0.82677 | 0.86614 | 0.90551 | 0.94488 | 0.98425 | 1.02362 | 1.06299 | 1.10236 | 1.14173 |
| 30 | 1.18110 | 1.22047 | 1.25984 | 1.29921 | 1.33858 | 1.37795 | 1.41732 | 1.45669 | 1.49606 | 1.53543 |
| 40 | 1.57480 | 1.61417 | 1.65354 | 1.69291 | 1.73228 | 1.77165 | 1.81102 | 1.85039 | 1.88976 | 1.92913 |
| 50 | 1.96850 | 2.00787 | 2.04724 | 2.08661 | 2.12598 | 2.16535 | 2.20472 | 2.24409 | 2.28346 | 2.32283 |
| 60 | 2.36220 | 2.40157 | 2.44094 | 2.48031 | 2.51969 | 2.55906 | 2.59843 | 2.63780 | 2.67717 | 2.71654 |
| 70 | 2.75591 | 2.79528 | 2.83465 | 2.87402 | 2.91339 | 2.95276 | 2.99213 | 3.03150 | 3.07087 | 3.11024 |
| 80 | 3.14961 | 3.18898 | 3.22835 | 3.26772 | 3.30709 | 3.34646 | 3.38583 | 3.42520 | 3.46457 | 3.50394 |
| 90 | 3.54331 | 3.58268 | 3.62205 | 3.66142 | 3.70079 | 3.74016 | 3.77953 | 3.81890 | 3.85827 | 3.89764 |
| 100 | 3.93701 | 3.97638 | 4.01575 | 4.05512 | 4.09449 | 4.13386 | 4.17323 | 4.21260 | 4.25197 | 4.29134 |
| 110 | 4.33071 | 4.37008 | 4.40945 | 4.44882 | 4.48819 | 4.52756 | 4.56693 | 4.60630 | 4.64567 | 4.68504 |
| 120 | 4.72441 | 4.76378 | 4.80315 | 4.84252 | 4.88189 | 4.92126 | 4.96063 | 5.00000 | 5.03937 | 5.07874 |
| 130 | 5.11811 | 5.15748 | 5.19685 | 5.23622 | 5.27559 | 5.31496 | 5.35433 | 5.39370 | 5.43307 | 5.47244 |
| 140 | 5.51181 | 5.55118 | 5.59055 | 5.62992 | 5.66929 | 5.70866 | 5.74803 | 5.78740 | 5.82677 | 5.86614 |
| 150 | 5.90551 | 5.94488 | 5.98425 | 6.02362 | 6.06299 | 6.10236 | 6.14173 | 6.18110 | 6.22047 | 6.25984 |
| 160 | 6.29921 | 6.33858 | 6.37795 | 6.41732 | 6.45669 | 6.49606 | 6.53543 | 6.57480 | 6.61417 | 6.65354 |
| 170 | 6.69291 | 6.73228 | 6.77165 | 6.81102 | 6.85039 | 6.88976 | 6.92913 | 6.96850 | 7.00787 | 7.04724 |
| 180 | 7.08661 | 7.12598 | 7.16535 | 7.20472 | 7.24409 | 7.28346 | 7.32283 | 7.36220 | 7.40157 | 7.44094 |
| 190 | 7.48031 | 7.51969 | 7.55906 | 7.59843 | 7.63780 | 7.67717 | 7.71654 | 7.75591 | 7.79528 | 7.83465 |
| 200 | 7.87402 | 7.91339 | 7.95276 | 7.99213 | 8.03150 | 8.07087 | 8.11024 | 8.14961 | 8.18898 | 8.22835 |
| 210 | 8.26772 | 8.30709 | 8.34646 | 8.38583 | 8.42520 | 8.46457 | 8.50394 | 8.54331 | 8.58268 | 8.62205 |
| 220 | 8.66142 | 8.70079 | 8.74016 | 8.77953 | 8.81890 | 8.85827 | 8.89764 | 8.93701 | 8.97638 | 9.01575 |
| 230 | 9.05512 | 9.09449 | 9.13386 | 9.17323 | 9.21260 | 9.25197 | 9.29134 | 9.33071 | 9.37008 | 9.40945 |
| 240 | 9.44882 | 9.48819 | 9.52756 | 9.56693 | 9.60630 | 9.64567 | 9.68504 | 9.72441 | 9.76378 | 9.80315 |
| 250 | 9.84252 | 9.88189 | 9.92126 | 9.96063 | 10.0000 | 10.0394 | 10.0787 | 10.1181 | 10.1575 | 10.1969 |
| 260 | 10.2362 | 10.2756 | 10.3150 | 10.3543 | 10.3937 | 10.4331 | 10.4724 | 10.5118 | 10.5512 | 10.5906 |
| 270 | 10.6299 | 10.6693 | 10.7087 | 10.7480 | 10.7874 | 10.8268 | 10.8661 | 10.9055 | 10.9449 | 10.9843 |
| 280 | 11.0236 | 11.0630 | 11.1024 | 11.1417 | 11.1811 | 11.2205 | 11.2598 | 11.2992 | 11.3386 | 11.3780 |
| 290 | 11.4173 | 11.4567 | 11.4961 | 11.5354 | 11.5748 | 11.6142 | 11.6535 | 11.6929 | 11.7323 | 11.7717 |
| 300 | 11.8110 | 11.8504 | 11.8898 | 11.9291 | 11.9685 | 12.0079 | 12.0472 | 12.0866 | 12.1260 | 12.1654 |
| 310 | 12.2047 | 12.2441 | 12.2835 | 12.3228 | 12.3622 | 12.4016 | 12.4409 | 12.4803 | 12.5197 | 12.5591 |
| 320 | 12.5984 | 12.6378 | 12.6772 | 12.7165 | 12.7559 | 12.7953 | 12.8346 | 12.8740 | 12.9134 | 12.9528 |
| 330 | 12.9921 | 13.0315 | 13.0709 | 13.1102 | 13.1496 | 13.1890 | 13.2283 | 13.2677 | 13.3071 | 13.3465 |
| 340 | 13.3858 | 13.4252 | 13.4646 | 13.5039 | 13.5433 | 13.5827 | 13.6220 | 13.6614 | 13.7008 | 13.7402 |
| 350 | 13.7795 | 13.8189 | 13.8583 | 13.8976 | 13.9370 | 13.9764 | 14.0157 | 14.0551 | 14.0945 | 14.1339 |
| 360 | 14.1732 | 14.2126 | 14.2520 | 14.2913 | 14.3307 | 14.3701 | 14.4094 | 14.4488 | 14.4882 | 14.5276 |
| 370 | 14.5669 | 14.6063 | 14.6457 | 14.6850 | 14.7244 | 14.7638 | 14.8031 | 14.8425 | 14.8819 | 14.9213 |
| 380 | 14.9606 | 15.0000 | 15.0394 | 15.0787 | 15.1181 | 15.1575 | 15.1969 | 15.2362 | 15.2756 | 15.3150 |
| 390 | 15.3543 | 15.3937 | 15.4331 | 15.4724 | 15.5118 | 15.5512 | 15.5906 | 15.6299 | 15.6693 | 15.7087 |
| 400 | 15.7480 | 15.7874 | 15.8268 | 15.8661 | 15.9055 | 15.9449 | 15.9843 | 16.0236 | 16.0630 | 16.1024 |
| 410 | 16.1417 | 16.1811 | 16.2205 | 16.2598 | 16.2992 | 16.3386 | 16.3780 | 16.4173 | 16.4567 | 16.4961 |
| 420 | 16.5354 | 16.5748 | 16.6142 | 16.6535 | 16.6929 | 16.7323 | 16.7717 | 16.8110 | 16.8504 | 16.8898 |
| 430 | 16.9291 | 16.9685 | 17.0079 | 17.0472 | 17.0866 | 17.1260 | 17.1654 | 17.2047 | 17.2441 | 17.2835 |
| 440 | 17.3228 | 17.3622 | 17.4016 | 17.4409 | 17.4803 | 17.5197 | 17.5591 | 17.5984 | 17.6378 | 17.6772 |
| 450 | 17.7165 | 17.7559 | 17.7953 | 17.8346 | 17.8740 | 17.9134 | 17.9528 | 17.9921 | 18.0315 | 18.0709 |
| 460 | 18.1102 | 18.1496 | 18.1890 | 18.2283 | 18.2677 | 18.3071 | 18.3465 | 18.3858 | 18.4252 | 18.4646 |
| 470 | 18.5039 | 18.5433 | 18.5827 | 18.6220 | 18.6614 | 18.7008 | 18.7402 | 18.7795 | 18.8189 | 18.8583 |
| 480 | 18.8976 | 18.9370 | 18.9764 | 19.0157 | 19.0551 | 19.0945 | 19.1339 | 19.1732 | 19.2126 | 19.2520 |
| 490 | 19.2913 | 19.3307 | 19.3701 | 19.4094 | 19.4488 | 19.4882 | 19.5276 | 19.5669 | 19.6063 | 19.6457 |

Table 5. (Continued) Millimeters to Inches
(Based on 1 inch = 25.4 millimeters, exactly)

Table 6. Fractional Inch — Millimeter and Feet — Millimeter Conversions
 (Based on 1 inch = 25.4 millimeters, exactly)

| Fractional Inch to Millimeters | | | | | | | |
|--------------------------------|-------|-----------------|--------|-----------------|--------|-----------------|--------|
| in. | mm | in. | mm | in. | mm | in. | mm |
| $\frac{1}{64}$ | 0.397 | $\frac{17}{64}$ | 6.747 | $\frac{33}{64}$ | 13.097 | $\frac{49}{64}$ | 19.447 |
| $\frac{1}{32}$ | 0.794 | $\frac{9}{32}$ | 7.144 | $\frac{17}{32}$ | 13.494 | $\frac{25}{32}$ | 19.844 |
| $\frac{3}{64}$ | 1.191 | $\frac{19}{64}$ | 7.541 | $\frac{35}{64}$ | 13.891 | $\frac{51}{64}$ | 20.241 |
| $\frac{1}{16}$ | 1.588 | $\frac{5}{16}$ | 7.938 | $\frac{9}{16}$ | 14.288 | $\frac{13}{16}$ | 20.638 |
| $\frac{5}{64}$ | 1.984 | $\frac{21}{64}$ | 8.334 | $\frac{37}{64}$ | 14.684 | $\frac{53}{64}$ | 21.034 |
| $\frac{3}{32}$ | 2.381 | $\frac{11}{32}$ | 8.731 | $\frac{19}{32}$ | 15.081 | $\frac{27}{32}$ | 21.431 |
| $\frac{7}{64}$ | 2.778 | $\frac{23}{64}$ | 9.128 | $\frac{39}{64}$ | 15.478 | $\frac{55}{64}$ | 21.828 |
| $\frac{1}{8}$ | 3.175 | $\frac{3}{8}$ | 9.525 | $\frac{5}{8}$ | 15.875 | $\frac{7}{8}$ | 22.225 |
| $\frac{9}{64}$ | 3.572 | $\frac{25}{64}$ | 9.922 | $\frac{41}{64}$ | 16.272 | $\frac{57}{64}$ | 22.622 |
| $\frac{5}{32}$ | 3.969 | $\frac{13}{32}$ | 10.319 | $\frac{21}{32}$ | 16.669 | $\frac{29}{32}$ | 23.019 |
| $\frac{11}{64}$ | 4.366 | $\frac{27}{64}$ | 10.716 | $\frac{43}{64}$ | 17.066 | $\frac{59}{64}$ | 23.416 |
| $\frac{3}{16}$ | 4.762 | $\frac{7}{16}$ | 11.112 | $\frac{11}{16}$ | 17.462 | $\frac{15}{16}$ | 23.812 |
| $\frac{13}{64}$ | 5.159 | $\frac{29}{64}$ | 11.509 | $\frac{45}{64}$ | 17.859 | $\frac{61}{64}$ | 24.209 |
| $\frac{7}{32}$ | 5.556 | $\frac{15}{32}$ | 11.906 | $\frac{23}{32}$ | 18.256 | $\frac{31}{32}$ | 24.606 |
| $\frac{15}{64}$ | 5.953 | $\frac{31}{64}$ | 12.303 | $\frac{47}{64}$ | 18.653 | $\frac{63}{64}$ | 25.003 |
| $\frac{1}{4}$ | 6.350 | $\frac{1}{2}$ | 12.700 | $\frac{3}{4}$ | 19.050 | 1 | 25.400 |

| Inches to Millimeters | | | | | | | |
|-----------------------|------|-----|-------|-----|-------|-----|-------|
| in. | mm | in. | mm | in. | mm | in. | mm |
| 1 | 25.4 | 3 | 76.2 | 5 | 127.0 | 7 | 177.8 |
| 2 | 50.8 | 4 | 101.6 | 6 | 152.4 | 8 | 203.2 |

| Feet to Millimeters | | | | | | | |
|---------------------|---------|-----|--------|----|---------|-----|--------|
| ft | mm | ft | mm | ft | mm | ft | mm |
| 100 | 30,480 | 10 | 3,048 | 1 | 304.8 | 0.1 | 30.48 |
| 200 | 60,960 | 20 | 6,096 | 2 | 609.6 | 0.2 | 60.96 |
| 300 | 91,440 | 30 | 9,144 | 3 | 914.4 | 0.3 | 91.44 |
| 400 | 121,920 | 40 | 12,192 | 4 | 1,219.2 | 0.4 | 121.92 |
| 500 | 152,400 | 50 | 15,240 | 5 | 1,524.0 | 0.5 | 152.40 |
| 600 | 182,880 | 60 | 18,288 | 6 | 1,828.8 | 0.6 | 182.88 |
| 700 | 213,360 | 70 | 21,336 | 7 | 2,133.6 | 0.7 | 213.36 |
| 800 | 243,840 | 80 | 24,384 | 8 | 2,438.4 | 0.8 | 243.84 |
| 900 | 274,320 | 90 | 27,432 | 9 | 2,743.2 | 0.9 | 274.32 |
| 1,000 | 304,800 | 100 | 30,480 | 10 | 3,048.0 | 1.0 | 304.80 |

Example 1: Find millimeter equivalent of 293 feet, $5\frac{47}{64}$ inches.

| | | |
|-----------------------------|---|---------------|
| 200 ft | = | 60,960. mm |
| 90 ft | = | 27,432. mm |
| 3 ft | = | 914.4 mm |
| 5 in. | = | 127.0 mm |
| $4\frac{47}{64}$ in. | = | 18,653 mm |
| 293 ft $5\frac{47}{64}$ in. | = | 89,452.053 mm |

Example 2: Find millimeter equivalent of 71.86 feet.

| | | |
|----------|---|---------------|
| 70. ft | = | 21,336. mm |
| 1. ft | = | 304.8 mm |
| .80 ft | = | 243.84 mm |
| .06 ft | = | 18.288 mm |
| 71.86 ft | = | 21,902.928 mm |

Table 7. Thousandths of an Inch to Millimeters Conversion Table

Greek Letters and Standard Abbreviations

The Greek letters are frequently used in mathematical expressions and formulas. The Greek alphabet is given below.

| | | | | | | | | | | | |
|----------|------------|---------|-----------|-------------|--------|----------|--------------------|---------|------------|------------|---------|
| A | α | Alpha | H | η | Eta | N | ν | Nu | T | τ | Tau |
| B | β | Beta | Θ | ϑ | Theta | Ξ | ξ | Xi | Υ | υ | Upsilon |
| Γ | γ | Gamma | I | ι | Iota | O | \circ | Omicron | Φ | ϕ | Phi |
| Δ | δ | Delta | K | κ | Kappa | Π | π | Pi | X | χ | Chi |
| E | ϵ | Epsilon | Λ | λ | Lambda | R | ρ | Rho | Ψ | ψ | Psi |
| Z | ζ | Zeta | M | μ | Mu | Σ | $\sigma \varsigma$ | Sigma | Ω | ω | Omega |

Roman Numerals

| | | | | | | | | | | | | | |
|-----|---|------|---|-----|----|------|----|-----|-----|------|-----|-----|------|
| I | 1 | V | 5 | X | 10 | L | 50 | C | 100 | D | 500 | M | 1000 |
| I | 1 | VI | 6 | XX | 20 | LX | 60 | CC | 200 | DC | 600 | MM | 2000 |
| II | 2 | VII | 7 | XXX | 30 | LXXX | 70 | CCC | 300 | DCC | 700 | IMM | 1999 |
| III | 3 | VIII | 8 | XL | 40 | LXXX | 80 | CD | 400 | DCCC | 800 | IL | 49 |
| IV | 4 | IX | 9 | XLV | 45 | XC | 90 | ID | 499 | CM | 900 | IC | 99 |

Rounding off Numbers

| Rules | Examples | | |
|--|--|--|--|
| When the last digit is followed by a 0,1,2,3,4, it is retained and unchanged. This is known as rounding down. | 3.60040 = 3.600 | | |
| When the last digit is followed by a 5,6,7,8 or 9, it is increased by 1. This is known as rounding up | 3.60027 = 3.600 | | |
| When the first digit neglected is a 5 followed by zeros the rounding is exactly equal to half a unit of the last digit retained. However, the last digit retained is then the closest even number. | 3.60070 = 3.601 3.60056 = 3.601 0.12500 = 0.12 0.15500 = 0.16 3.60350 = 3.604 3.60450 = 3.604 | | |

Table 8. Functions of π

| Constant | Numerical Value | Logarithm | Constant | Numerical Value | Logarithm |
|----------------|-----------------|-----------|----------------|-----------------|-----------|
| π | 3.141593 | 0.49715 | 2π | 6.283185 | 0.79818 |
| 3π | 9.424778 | 0.97427 | 4π | 12.566370 | 1.09921 |
| $2\pi/3$ | 2.094395 | 0.32105 | $4\pi/3$ | 4.188790 | 0.62209 |
| $\pi/2$ | 1.570796 | 0.19611 | $\pi/3$ | 1.047197 | 0.02003 |
| $\pi/4$ | 0.785398 | -0.10491 | $\pi/6$ | 0.523598 | -0.28100 |
| $\pi\sqrt{2}$ | 4.442882 | 0.64766 | $\pi\sqrt{3}$ | 5.441398 | 0.73571 |
| $\pi/\sqrt{2}$ | 2.221441 | 0.34663 | $\pi/\sqrt{3}$ | 1.813799 | 0.25859 |
| π^2 | 9.869604 | 0.99430 | $1/\pi^2$ | 0.101321 | -0.99430 |
| $1/\pi$ | 0.318310 | -0.49715 | $1/2\pi$ | 0.159155 | -0.79818 |
| $1/\pi^3$ | 0.032252 | -1.49145 | π^3 | 31.006277 | 1.49145 |
| $\sqrt{\pi}$ | 1.772454 | 0.24858 | $3/\pi$ | 1.464592 | 0.16572 |

Table 9. Functions of g

| Constant | Numerical Value, ft/s ² | Numerical Value, m/s ² | Constant | Numerical Value | Numerical Value, m/s ² |
|----------------|------------------------------------|-----------------------------------|-------------------|-----------------|-----------------------------------|
| g | 32.16 | 9.81 | g^2 | 1034.266 | 96.2361 |
| $2g$ | 64.32 | 19.62 | $1/2g$ | 0.01555 | 0.101936 |
| $\sqrt{2}g$ | 8.01998 | 4.43 | $1/\sqrt{g}$ | 0.17634 | 0.319275 |
| π/\sqrt{g} | 0.55398 | 1.00 | $\pi/(2\sqrt{g})$ | 0.39172 | 0.70916 |

Table 10. Functions of e

| Constants | Numerical value | Constants | Numerical value |
|-----------|-----------------|-----------|-----------------|
| e | 2.71828 | $1/e$ | 0.3679 |
| $1/e^2$ | 0.13534 | e^π | 23.141 |

Table 11. Fundamental Constants

| Constant | Symbol | Value | |
|--------------------------|--------------------------|---|---|
| | | SI Units | Other Units |
| Electronic Charge | e | 1.60210×10^{-19} C | 4.80298×10^{-10} e.s.u. |
| Electronic rest mass | m_e | 9.1091×10^{-31} kilogram | 5.48597×10^{-4} a.m.u |
| Electronic radius | r_e | 2.81777×10^{-15} meter | ... |
| Proton rest mass | m_p | 1.67252×10^{-27} kilogram | 1.00727663 a.m.u |
| Neutron rest mass | m_n | 1.67482×10^{-27} kilogram | 1.0086654 a.m.u |
| Planck's constant | h | 6.62559×10^{-34} joule second | 6.62559×10^{-27} erg second |
| Velocity of Light | c | 2.997925×10^8 meters/s | 186281 miles/s |
| Avogadro's constant | L, N_A | 6.02252×10^{23} per mole | ... |
| Loschmidt's Constant | N_l | $2.68719 \times 10^{25} \text{ m}^{-3}$ | $2.68719 \times 10^{19} \text{ cm}^{-3}$ |
| Gas Constant | R | $8.3143 \text{ J K}^{-1} \text{ mol}^{-1}$ | $1.9858 \text{ calories } ^\circ\text{C}^{-1} \text{ mol}^{-1}$ |
| Boltzmann's constant | $\kappa = \frac{R}{N_A}$ | $1.38054 \times 10^{-23} \text{ J K}^{-1}$ | $3.29729 \times 10^{-24} \text{ calories } ^\circ\text{C}^{-1}$ |
| Faraday's Constant | F | $9.64870 \times 10^4 \text{ Coulomb mol}^{-1}$ | $2.89261 \times 10^{14} \text{ e.s.u mol}^{-1}$ |
| Stefan-Boltzman Constant | σ | $5.6697 \times 10^{-8} \text{ W m}^{-2} \text{ K}^4$ | $5.6697 \times 10^{-5} \text{ e.s.u. mol}^{-1}$ |
| Gravitational Constant | G | $6.670 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ | $6.670 \times 10^{-11} \text{ dyne cm}^2 \text{ g}^{-2}$ |
| Electrical Permeability | μ_0 | $4\pi \times 10^{-7} \text{ H m}^{-1}$ | ... |
| Magnetic Permeability | ϵ_0 | $8.85418 \times 10^{-12} \text{ F m}^{-1}$ | ... |
| Eulers Constant | γ | 0.5772 | ... |
| Golden Ratio | Φ | 1.6180 | ... |

Table 12. Weights and Volumes

| Constant | Numerical Value | Logarithm |
|---|-----------------|-----------|
| Weight in pounds of: | | |
| Water column, 1" × 1" × 1 ft. | 0.4335 | -0.36301 |
| 1 U.S. gallon of water, 39.1°F. | 8.34 | 0.92117 |
| 1 cu. ft. of water, 39.1°F. | 62.4245 | 1.79536 |
| 1 cu. in. of water, 39.1°F. | 0.0361 | -1.44249 |
| 1 cu. ft. of air, 32°F., atmospheric pressure | 0.08073 | -1.09297 |
| Volume in cu. ft. of: | | |
| 1 pound of water, 39.1°F | 0.01602 | -1.79534 |
| 1 pound of air, 32°F., atmospheric pressure | 12.387 | 1.09297 |
| Volume in gallons of 1 pound of water, 39.1°F | 0.1199 | -0.92118 |
| Volume in cu.in of 1 pound of water, 39.1 °F | 27.70 | 1.44248 |
| Gallons in one cubic feet | 7.4805 | 0.87393 |
| Atmospheric pressure in pounds per sq. inch | 14.696 | 1.16720 |

Table 13. Conversion Factors

| Multiply | By | To Obtain |
|--------------------------|------------------------|-----------------------|
| Celsius | $C \times 1.8 + 32$ | Fahrenheit |
| Celsius | $C + 273.15$ | Kelvin |
| Circumference | 6.2832 | radians |
| Degrees/second (angular) | 0.002778 | revolutions/sec |
| Degrees (angular) | 60 | minutes |
| Degrees (angular) | 0.01111 | quadrants |
| Degrees/second (angular) | 0.01745 | radians/sec |
| Degrees (angular) | 3600 | seconds |
| Degrees (angular) | 0.01745 | radians |
| Degrees/second (angular) | 0.1667 | revolutions/min (rpm) |
| Fahrenheit | $F + 459.67$ | Rankine |
| Fahrenheit | $[F - 32] \times 5/9$ | Celsius |
| Horsepower | 0.7457 | kilowatts |
| Horsepower | 33,000 | foot-pounds/min |
| Horsepower | 550 | foot-pounds/sec |
| Horsepower | 745.7 | watts |
| Horsepower-hr | 2.6845×1013 | ergs |
| Horsepower-hr | 0.7457 | kilowatt-hrs |
| Horsepower-hr | 1.98×106 | foot-pounds |
| Minutes (angular) | 60 | seconds |
| Minutes (angular) | 2.909×10^{-4} | radians |
| Minutes (angular) | 1.852×10^{-4} | quadrants |
| Minutes (angular) | 0.01667 | degrees |
| Quadrants (angular) | 5400 | minutes |
| Quadrants (angular) | 1.571 | radians |
| Quadrants (angular) | 90 | degrees |
| Radians/sec | 57.3 | degrees/sec |
| Radians/sec | 9.549 | revolutions/min |
| Radians/sec | 0.1592 | revolutions/sec |
| Radians | 0.6366 | quadrants |
| Radians | 57.3 | degrees |
| Radians | 3438 | minutes |
| Rankine | R-459.67 | Fahrenheit |
| Revolutions/min | 0.1047 | radians/sec |
| Revolutions/min | 0.01667 | revolutions/sec |
| Revolutions/sec | 360 | degrees/sec |
| Revolutions/sec | 6.283 | radians/sec |
| Revolutions/min | 6 | degrees/sec |
| Revolutions/sec | 60 | revolutions/sec |
| Revolutions | 6.283 | radians |
| Revolutions | 4 | quadrants |
| Revolutions | 360 | degrees |
| Seconds (angular) | 4.848×10^{-6} | radians |
| Seconds (angular) | 3.087×10^{-6} | quadrants |
| Seconds (angular) | 0.01667 | minutes |
| Seconds (angular) | 2.778×10^{-4} | degrees |

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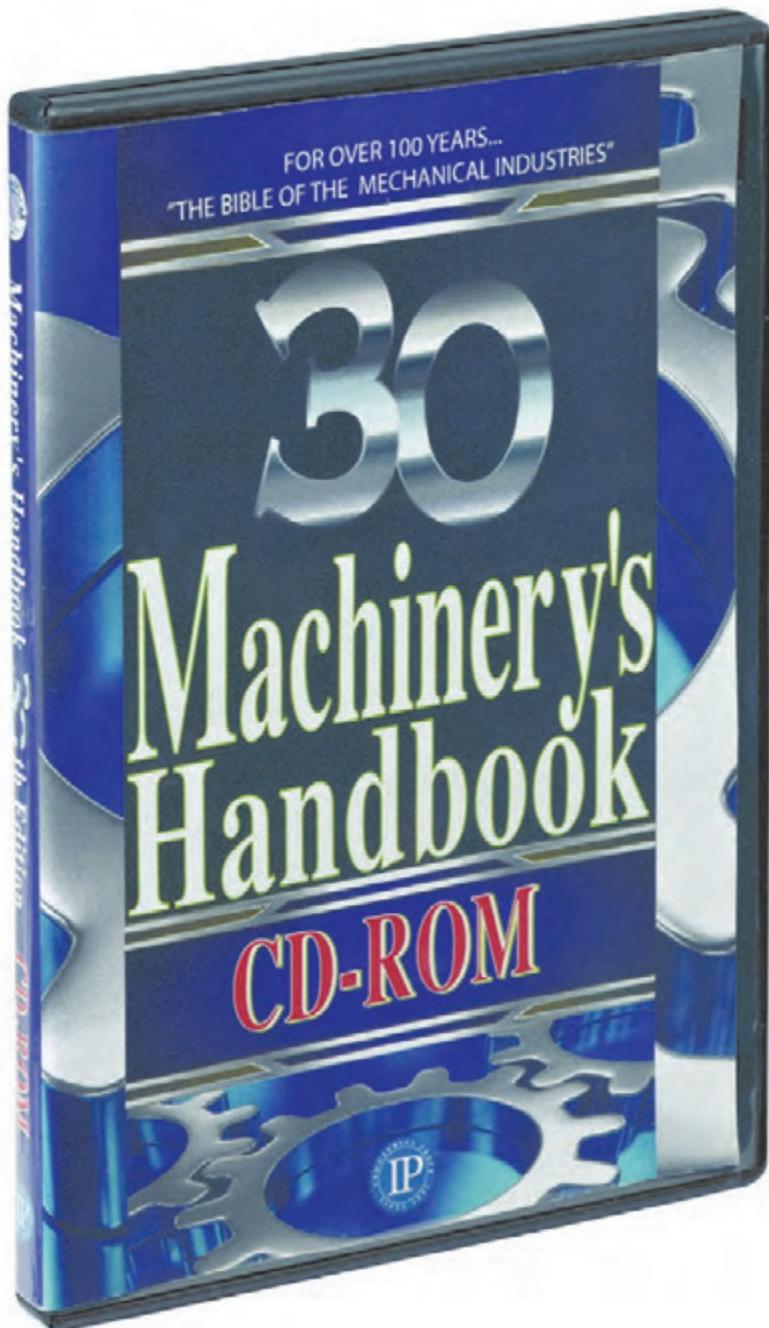
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